CORPS OF ENGINEERS, U. S. ARMY

PLANS FOR REDUCTION OF SHOALING IN RARITAN RIVER, NEW JERSEY

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-342

WATERWAYS EXPERIMENT STATION

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PREFACE

The Waterways Experiment Station conducted the investigation described herein at the request of the New York District, Corps of Engineers. The study was initiated in August 1947 and, after completion of preliminary tests, was suspended while a prototype sediment survey was made by the New York District. Testing was resumed in March 1950 and completed in June 1951.

Engineers of the Hydraulics Division of the Waterways Experiment Station actively connected with the investigation were Messrs. G. B. Fenwick, H. B. Simmons, T. J. Kinzer, and model technicians were Messrs. W. A. Moore and R. V. Puckett.

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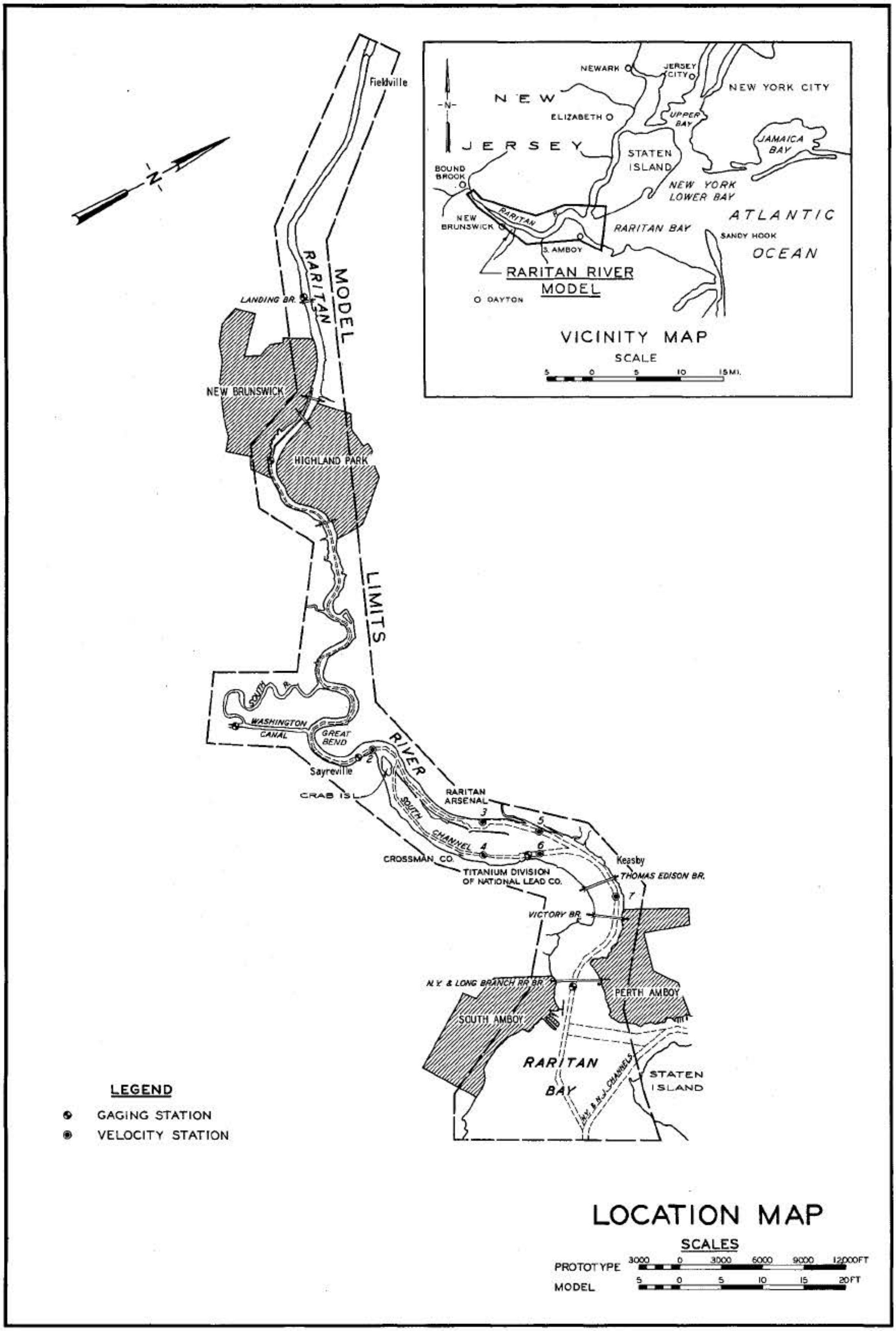
SUMMARY

A hydraulic model investigation was conducted of Raritan River, New Jersey, to determine some means of minimizing the excessive rate of shoaling in the 25-ft reach of the south channel of the river. A fixed-bed model, scale ratios of 1:600 horizontally and 1:100 vertically, was used.

Model tests indicated that realignment of a portion of the 25-ft section of south channel, together with closure of the main channel by a dike, would afford the maximum reduction of shoaling in the problem area but would probably increase shoaling in the Raritan Arsenal turning basin located in the main channel. The dike must have a top elevation of not higher than mean high water in order to pass high fresh-water flows safely.



VICINITY MAP
SCALE
NEWARK
JERSEY CITY
NEW YORK CITY
NEW
ELIZABETH
UPPER BAY
JAMAICA BAY
JERSEY
STATEN ISLAND
BOUND BROOK
NEW YORK LOWER BAY
ATLANTIC
OCEAN
NEW BRUNSWICK
RARITAN
RARITAN BAY
SANDY HOOK
S. AMBOY
RARITAN RIVER MODEL
DAYTON
Fieldville
MODEL
RARITAN
LANDING BR.
NEW BRUNSWICK
HIGHLAND PARK
LIMITS
SOUTH R.
WASHINGTON CANAL
GREAT BEND
RIVER
Sayreville
CRAB ISL.
RARITAN ARSENAL
SOUTH CHANNEL
CROSSMAN CO.
TITANIUM DIVISION OF NATIONAL LEAD CO.
Keasby
THOMAS EDISON BR.
VICTORY BR.
N.Y. & LONG BRANCH RR BR.
PERTH AMBOY
SOUTH AMBOY
RARITAN BAY
N.Y. & N.J. CHANNELS
STATEN ISLAND
LEGEND
GAGING STATION
VELOCITY STATION
LOCATION MAP
SCALES
PROTOTYPE
MODEL

Fig. 1

PLANS FOR REDUCTION OF SHOALING IN RARITAN RIVER, NEW JERSEY

Model Investigation

PART I: INTRODUCTION

The Prototype

1. Raritan River rises in north-central New Jersey and flows southeasterly into Raritan Bay, between Perth Amboy and South Amboy, about 24 miles by water south of the Battery, New York City (see fig. 1). The upper section of the river consists of the North and South Branches, which flow southward a distance of 21 and 48 miles, respectively, to their junction 18 miles above New Brunswick, N. J. Thence the river flows 30 miles southeastward into Raritan Bay. The total drainage area is 1,105 square miles. The average fresh-water discharge at the mouth is about 1700 cfs. The maximum and minimum discharges are 80,000 cfs and 50 cfs, respectively.

2. Improvements authorized by Congress consist of a main channel 25 ft deep and 300 ft wide from its junction with New York and New Jersey Channels to the Government Wharf at Raritan Arsenal, thence 15 ft deep and 200 ft wide to Washington Canal, thence 10 ft deep and 100 ft wide to New Brunswick (fig. 1). The authorized improvements also include a south channel 25 ft deep and 300 ft wide extending from its downstream junction with the main channel at Keasby, to a point opposite the upper end of the property of the National Lead Co., thence 10 ft deep and 150 ft wide to its upstream junction with the main channel at Crab Island.

The authorized 25-ft by 300-ft channel from the junction of south and main channels to the Raritan Arsenal is presently maintained at 20 ft by 300 ft because of navigation requirements. The authorized 10-ft by 150-ft portion of the south channel is presently maintained only to Crossman's Wharf.

3. The width of the river between banks ranges from 4,000 ft near the mouth to 400 ft near New Brunswick. The river is tidal for a distance of 18 miles above its mouth. The mean ranges of tide at Perth Amboy and New Brunswick are 5.1 and 5.5 ft, respectively.

The Problem

4. The river between Crab Island and Keasby in its original condition had only one channel, on the north side, about 6 to 7 ft deep. No natural channel existed on the south side, where depths were about 2 ft. A south channel was originally provided in 1883. Several increases in project depth were authorized in subsequent years. The existing 25-ft-deep project in the south channel was adopted in 1937, and the initial dredging to this depth was performed in 1940-1942. Maintenance operations were completed in September 1944, with 780,000 cu yd of material having been removed. A survey in February 1945 indicated that 560,000 cu yd of material had settled in the 25-ft-deep reach of the channel, representing about 9 ft of shoaling in five months. Shoaling for various periods subsequent to dredging is shown on plate 1.

5. South channel, subsequent to the 1944 maintenance dredging to 25 ft, was receiving a monthly discharge of around 10,000 tons of ferrous sulfate. This discharge was gradually increased to an estimated 11,000 tons by June 1948 and then was gradually discontinued during the period

July to November 1948. The effect of this discontinuance may be seen on the shoaling-rate curve on plate 1; however, the shoaling rate continued to be high. A model investigation of the problem was authorized primarily with a view to determining some means of minimizing the excessive rate of shoaling in the 25-ft section of south channel.

PART II: THE MODEL

Description

6. The Raritan River model was a scale reproduction of about 22 miles of the river and included portions of Raritan Bay, South River, and Washington Canal. The model layout is shown on fig. 1.

7. The model was of the fixed-bed type, all channel and overbank areas being molded in concrete. Overbank areas were molded to an elevation of 18 ft above mean low water at South Amboy, and channel areas were molded to hydrographic surveys made by the New York District and by the State of New Jersey. Figs. 2 and 3 show general views of the model.

Scale ratios

8. Scale ratios, model to prototype, were 1:600 horizontally and

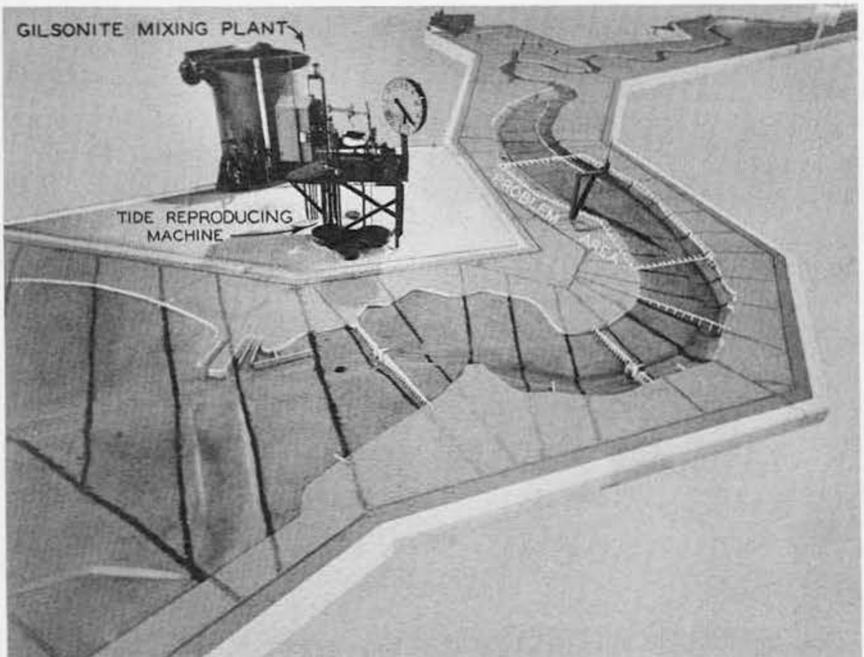


Fig. 2. General view of model looking upstream from Raritan Bay

1:100 vertically. Other scale ratios, computed from the linear scale ratios according to the Froudian relationship, were as follows:

Velocity	1:10
Time	1:60
Discharge	1:600,000

Appurtenances

9. Automatic tide reproducer. The rise and fall of the tide and the accompanying tidal currents in the model river were obtained by reproducing the proper rise and fall of the tide in the model bay. An automatic tide reproducer was used for this purpose and consisted essentially of the following components: (a) a main header sloping from the model to a nearby water-supply sump; (b) a pump supplying through a separate line a constant flow from the sump into the main header; (c) a motorized, commercial rising-stem valve installed in the main header at a point about 3 ft toward the sump from the point of entrance of the pump line into the header; and (d) an automatic control apparatus located within the model for

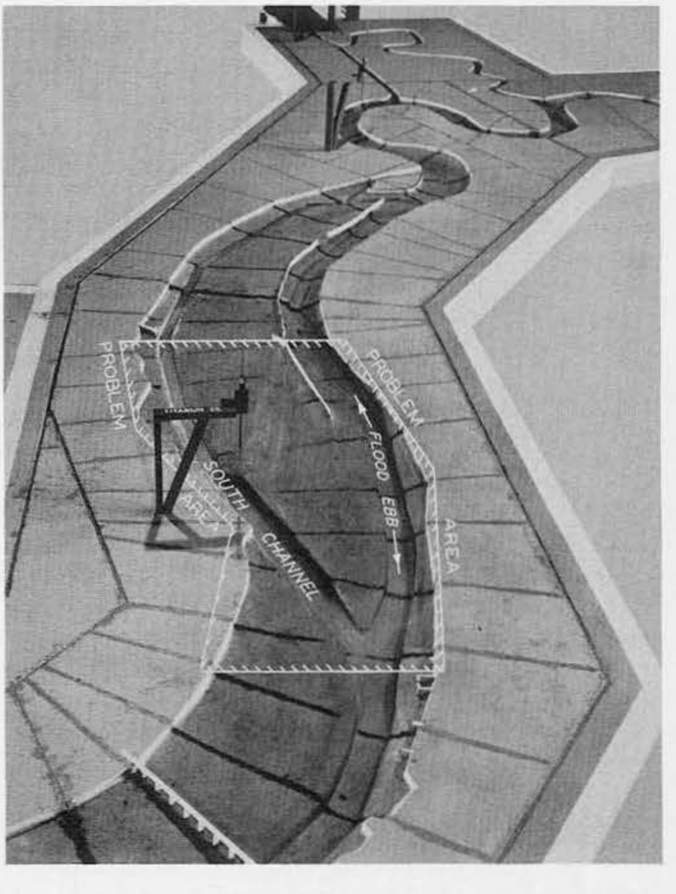


Fig. 3. Upstream view of south channel problem area

regulating the operation of the valve by means of a system of floats and electric contacts. A complete closure of the valve would divert the entire output from the pump into the model, creating a rapidly flooding tide; whereas, a complete opening of the valve would allow not only the pump output but also gravity flow from the model to return to the sump and thus create a rapidly ebbing tide. Thus, any desired rate of ebb or flood could be obtained by proper control of the valve.

10. Automatic tide apparatus. The automatic tide-control apparatus was equipped with a cam, cut to a polar plot of the prototype tide, rotated by an electric motor at a speed determined by the computed time scale. Riding vertically upon this cam was a follower bearing a pair of electric contacts, one above the other, which rotation of the cam caused to rise and fall in accordance with the plotted tide curve. A third contact, placed between this pair of contacts with 0.001-ft clearances above and below, was mounted upon a rod riding a float in the control pit, which was freely connected with the model ocean by means of pipes. An error in the water-surface elevation in the model of magnitude equal to or greater than that of the clearances thus caused the circuit to close, and movement of the valve resulted. The need was anticipated for a certain amount of valve movement to produce the necessary change in the direction of the movement of the water surface at low tide and high tide; consequently, a secondary circuit was used to impart a predetermined motion to the valve.

11. Automatic tide recorder. The automatic control apparatus described above was equipped with a recording device which inked on an unrolling paper strip a continuous record of the model tide curve,

superimposed upon the prototype curve being reproduced. The prototype curve was inked by a pen riding the contact-bearing cam follower, while the model curve was superimposed by a pen fixed to a staff riding a float in the control pit. This feature permitted a visual check on the model tide reproduction at all times.

12. Tributary control gate. The necessity for reproducing extensive reaches of South River and Washington Canal was precluded by reproducing tidal elevations and discharges at the cutoff points in these streams. This was accomplished in each case by means of a movable vertical gate, installed at the model cutoff point and controlled by a cam driven by a motor synchronous with that driving the tide-control mechanism. A constant flow of water was discharged from a Van Leer weir into the terminal pit. The gate was operated in such manner that tidal phenomena in South River and Washington Canal were reproduced to scale without including in the model the entire tidal prism of these streams.

13. Raritan River discharge weir. The necessary river discharge was introduced at the upper end of the model by a 2-in. Van Leer weir supplied from a constant-head tank.

14. Tide gages. Tidal elevations were measured in the model by means of point gages graduated to read to the nearest 0.001 ft. Permanent gages were located to correspond with the location of all prototype gages for which tidal data were available.

15. Current velocity meters. Current velocity measurements were obtained in the model by means of miniature Price-type current meters. The meters used were approximately one inch in diameter, and the meter cups were about 0.025 ft in diameter. The meters were calibrated

periodically to insure accurate determination of current velocities.

16. Shoaling apparatus. Shoaling was simulated in the model by means of finely ground gilsonite, an asphaltic compound having a specific gravity of about 1.035. The gilsonite was crushed and graded, then mixed with water for introduction into the model. The mixture was placed in a circular tank, equipped with propellers to insure a proper mixing, and was distributed to the model through a system of pumps, pipes, and valves. Material deposited in the model at the end of a shoaling test was picked up by a small suction pump for measurement.

General Test Procedure

17. The sequence of the various phases of the model study was as follows: (a) hydraulic adjustment of the model; (b) preliminary shoaling adjustment; (c) preliminary tests of proposed improvement plans; (d) revised shoaling adjustment; (e) final tests of proposed improvement plans; and (f) final tests of various modifications of the best improvement plan. These phases are discussed in detail in subsequent parts of this report.

PART III: VERIFICATION OF THE MODEL

18. A hydraulic model of the type used in the investigation reported herein must demonstrate its ability to reproduce with reasonable accuracy all significant phenomena of the prototype before tests of proposed improvement works are undertaken. It was desired that tests on the Raritan River model indicate the effects of the proposed improvement plans on both hydraulic phenomena (tidal heights, current velocities, and current directions) and the deposition of shoaling material throughout the problem area; therefore, verification of the model with respect to both hydraulic and shoaling phenomena was required.

Hydraulic Verification

19. The first step in the hydraulic adjustment of the model was adjustment of the electro-mechanical tide reproducer so that it reproduced accurately the tidal phenomena of the prototype in the Raritan Bay portion of the model. When this had been accomplished, the river tides were adjusted by adding roughness in the form of small rocks stuccoed to the bottom of the model channels to reproduce the correct prototype roughness. Very little roughness was required for the Raritan River model, since velocities in the prototype were so low that the frictional resistance of the bed and banks was of little significance.

Tidal heights and current velocities

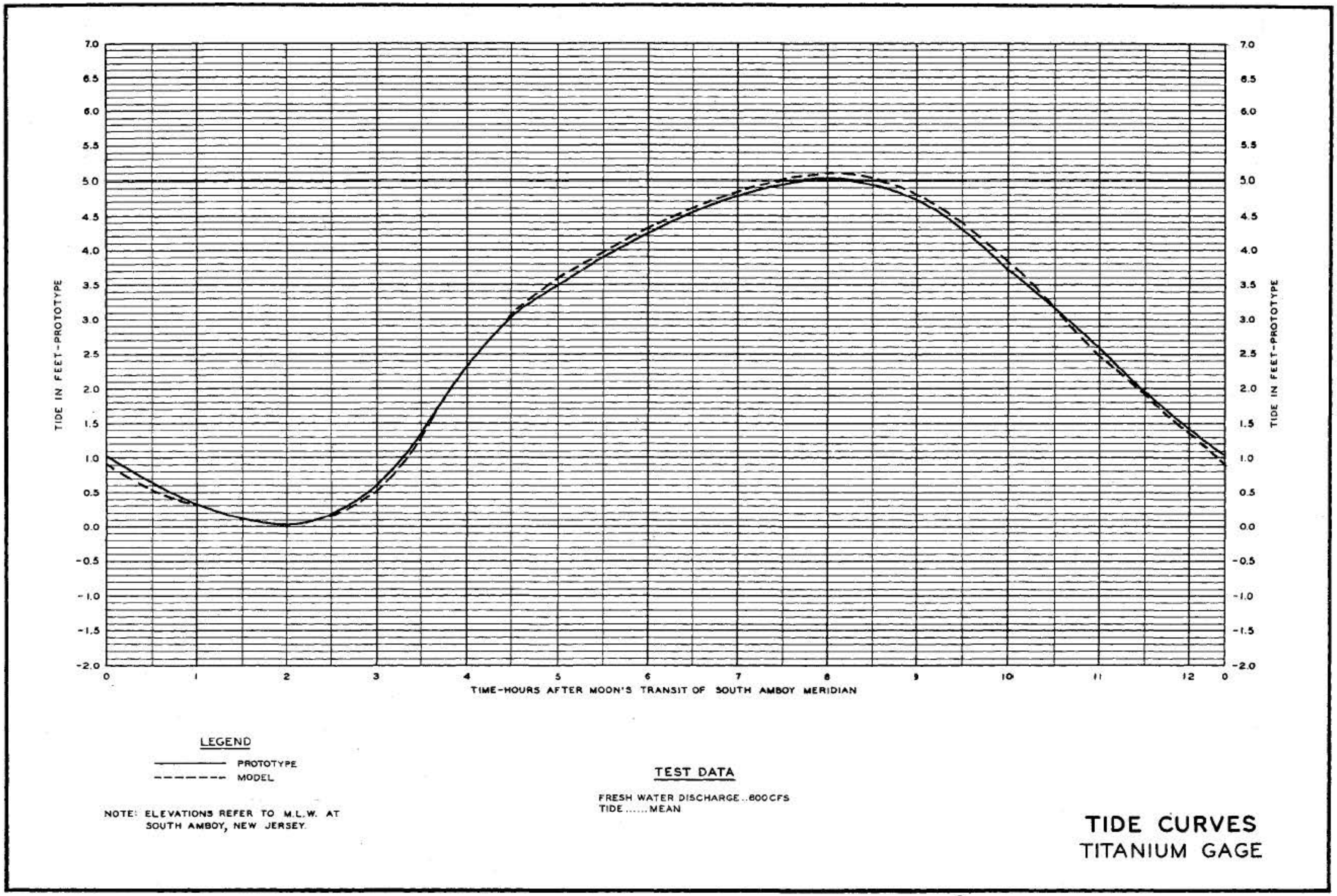
20. Prototype current velocities for 6 ranges (see velocity stations on fig. 1) were obtained for 22 August 1947. The fresh-water discharge for this date was 749 cfs at Bound Brook and 973 cfs at South

Amboy, and the tidal range at South Amboy was 4.6 ft, or 0.5 ft less than the mean range. The elevation of mean low water at South Amboy is -2.6 ft msl. It was decided to reproduce a tide of more nearly mean proportions and to correct the current velocities to it. The tide of 3 October, having a range of 5.1 ft and a low-water elevation of -2.16 ft msl, was chosen for this purpose. The fresh-water discharge for this date was 182 cfs at Bound Brook. As no tidal data for Landing Bridge or South River were available for this date, it was necessary to use data obtained at those points on days when the tides were similar (11 December 1947 for Landing Bridge and 14 December for South River). The fresh-water discharges at Bound Brook for these dates were 601 and 455 cfs, respectively. The times and elevations of high and low water for prototype and model are shown in table 1.

21. Mean tide curves, model and prototype, for the Titanium gage are shown on fig. 4. A comparison of model and prototype velocities, together with times of slack water, is shown in table 2. A study of the prototype vertical velocity profiles for the stations shown on fig. 1 indicated that density currents in the prototype were negligible. Therefore, use of salt water in the ocean was not necessary, and adjustment of the model was made with fresh water only.

Initial Shoaling Verification

22. It was generally believed at the inception of the model study that most of the material shoaling the 25-ft portion of south channel was moved downstream through the shallow portion of that channel to the 25-ft-deep section, where the larger cross-sectional area and accompanying low



TIDE IN FEET-PROTOTYPE
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0 1 2 3 4 5 6 7 8 9 10 11 12 0
TIME-HOURS AFTER MOON'S TRANSIT OF SOUTH AMBOY MERIDIAN
LEGEND
PROTOTYPE
MODEL
NOTE: ELEVATIONS REFER TO M.L.W. AT SOUTH AMBOY, NEW JERSEY
TEST DATA
FRESH WATER DISCHARGE..800 CFS
TIDE......MEAN
TIDE CURVES
TITANIUM GAGE

Fig. 4

current velocities caused rapid deposition. Therefore, the first attempt at reproduction of shoaling in the model involved introduction of all shoaling material on a range just above Crab Island, and only during ebb tides. However, it was found that little of this material moved into south channel from upstream. Instead, it moved downstream in main channel to and beyond the downstream junction of main and south channels during ebb tides and thence moved upstream into south channel during flood tides. The reason for this action appeared to be that most of the water flowing into south channel during flood tides came from the lower strata of the river where the greatest amount of shoaling material was concentrated. These somewhat surprising results led to a re-evaluation of the problem and of the prototype data available.

23. A study of the results of the initial shoaling adjustment tests by engineers of the Waterways Experiment Station and the New York District indicated that additional prototype data on shoaling characteristics of the problem area were necessary. It was also decided that verification of shoaling in south and main channels simultaneously appeared desirable, instead of in south channel only as was first contemplated. Accordingly, a new survey was undertaken in the prototype for the purpose of obtaining sufficient data to permit a proper understanding of the prototype shoaling phenomena, and to provide a sound basis for shoaling adjustment of the model.

New prototype survey

24. The new prototype survey consisted of hydrographic surveys of south and main channels, computations of shoaling rates in these two channels, observation of mean daily discharges and turbidity at Bound Brook,

observations of turbidity and sediment flow in Raritan River, mechanical analyses of samples from the bed at several stations in the river and bay, and chemical and physical analyses of water samples taken at several stations in the river and bay.

25. The suspended sediment study in the prototype (included in the new survey) indicated that even in dry weather the total sediment flow in the river at the problem area during one complete ebb tide was usually greater than 500 tons, while the corresponding flow at Bound Brook (see vicinity map, fig. 1), which accounts for 70 per cent of the total drainage area, was less than 10 tons. The comparatively high sediment flow at the problem area was attributed by the New York District Office to industrial and sanitary wastes discharged into the tidal section of the river. The study also established the fact that sediment flow at the problem area during flood tide averages only about 15 per cent less than the ebb sediment flow. Apparently, the sediment oscillates with the tide several times before being deposited or discharged by the seaward drift of the river. This seaward drift was found by the Woods Hole Oceanographic Institution to be about one-half mile per day.

26. The New York District, at the time of the prototype survey, was engaged in maintenance dredging operations in both south and main channels, a situation which had not occurred at any time previously. The district was requested to obtain simultaneous after-dredging data in both channels, and the data obtained are presented on plate 2. The 25-ft section of south channel shoaled 295,000 cu yd during the period March-December 1949. The 25-ft section of main channel between its junction with south channel and the upper end of the 25-ft project shoaled 150,000

cu yd during the period March-September 1949. Correcting this latter figure pro rata for time, the ratio of shoaling in the two channels was $\frac{225,000}{295,000}$, or 57 per cent in south channel and 43 per cent in main channel.

Verification to new shoaling data

27. In applying these new data to the model, consideration was given to the fact that the immediate source of considerable amounts of shoaling material was downstream, rather than upstream, from the problem area. Accordingly, a gilsonite-injection range was established 1000 ft downstream from Edison Bridge for the introduction of material during flood tides, and the range above Crab Island was used for introduction of material during ebb tides. This procedure permitted both ebb and flood currents to transport material into and through the problem area in a manner similar to the prototype occurrence.

28. It was found by a few trial tests that model shoaling material was readily transported upstream at fresh-water river flows of 800 cfs or less, and downstream at flows of 4000 cfs or more. Examination of river hydrographs for the period 1946-1949 indicated that the mean low discharge was about 800 cfs, and that peak flows in excess of 4000 averaged about 8000 cfs. On this basis, an operating technique was devised in which the inflow was varied from 800 cfs to 8000 cfs for alternate periods of 1.5 cycles in order to distribute the effects of the high and low fresh-water flows throughout the tests. Material was introduced at the upstream range during ebb tide and high fresh-water discharge, and at the downstream range during flood tide and low fresh-water discharge (plate 4 shows the relation between fresh-water discharge and injection of shoal material).

PART IV: NARRATIVE OF TESTS

Base Tests

Purpose

29. In order to evaluate the effects of the proposed improvement plans on hydraulic and shoaling phenomena, it was first necessary to establish hydraulic and shoaling "base tests" which depicted, respectively, the hydraulic and shoaling characteristics throughout the model for existing conditions. Thus, a test in which no improvement plan was installed in the model is referred to as a "base test," since its results constitute a basis of comparison for determining the effects of improvement plans.

Hydraulic base test

30. Basic hydraulic data were obtained for conditions of mean tide and mean fresh-water discharge, since hydraulic tests of proposed improvement plans were to be made for mean conditions only. Hydraulic data obtained consisted of measurements of tidal heights and current velocities at critical stations throughout the model. These data are presented in tables 4 and 5, together with comparable hydraulic data obtained during subsequent tests of proposed improvement plans.

Shoaling base tests

31. A total of four shoaling base tests was made during the course of the model study. The reasons for each of the shoaling base tests, and the plan tests compared to each base test, are outlined in the following subparagraphs:

- a. The initial shoaling base test was the same as the initial shoaling verification test, described in paragraphs 22 and 23. As explained in the referenced paragraphs, this test

was based upon the original erroneous assumption that the source of all material shoaling south channel was upstream, and all model shoal material was therefore injected at the Crab Island range during ebb tides. The results of this base test (presented in table 3) were used to evaluate the results of preliminary tests of plans 3, 4, and 5. These preliminary tests were made while the new prototype survey was in progress, with a view to obtaining tentative rough indications of the effectiveness of the plans.

b. The second shoaling base test was made following receipt of data from the new prototype survey described in paragraphs 24 through 26, and was the same as the shoaling verification test described in paragraphs 27 and 28. The results of this base test (presented in table 6) were used to evaluate the results of final tests of plans 3, 4, 5, and 6.

c. The original supply of model shoaling material was exhausted during tests described in a and b above, and a new supply of material was obtained and processed. A check test was made of the base test described in b above to determine whether the characteristics of the new material were the same as the original, and it was found that the distribution of material throughout the problem area was somewhat different. Therefore, a new base test, the third, was established to evaluate the results of plans tested with the new shoaling material. The results of the third base test (presented in table 7) were used to evaluate the results of tests of plans 3A, 3B, 3C, and 3D.

d. The distribution of shoaling material throughout the problem area of the model was somewhat closer to that of the prototype for the base test described in b above than for that described in c. An analysis of model shoaling material used for the two tests revealed that the grain-size distribution differed slightly. Therefore, before conducting final tests of the most promising improvement plans, a new supply of shoaling material was processed to conform to the characteristics of the material used for the base test described in b above, and a new base test was made with this material. The results of this fourth base test (presented in table 8) were used to evaluate the results of tests of plans 3 modified, 3D modified, 3G, and 3H.

First Series (before New Prototype Survey)

Plan 3

32. Description. The elements of plan 3 are shown of fig. 5.

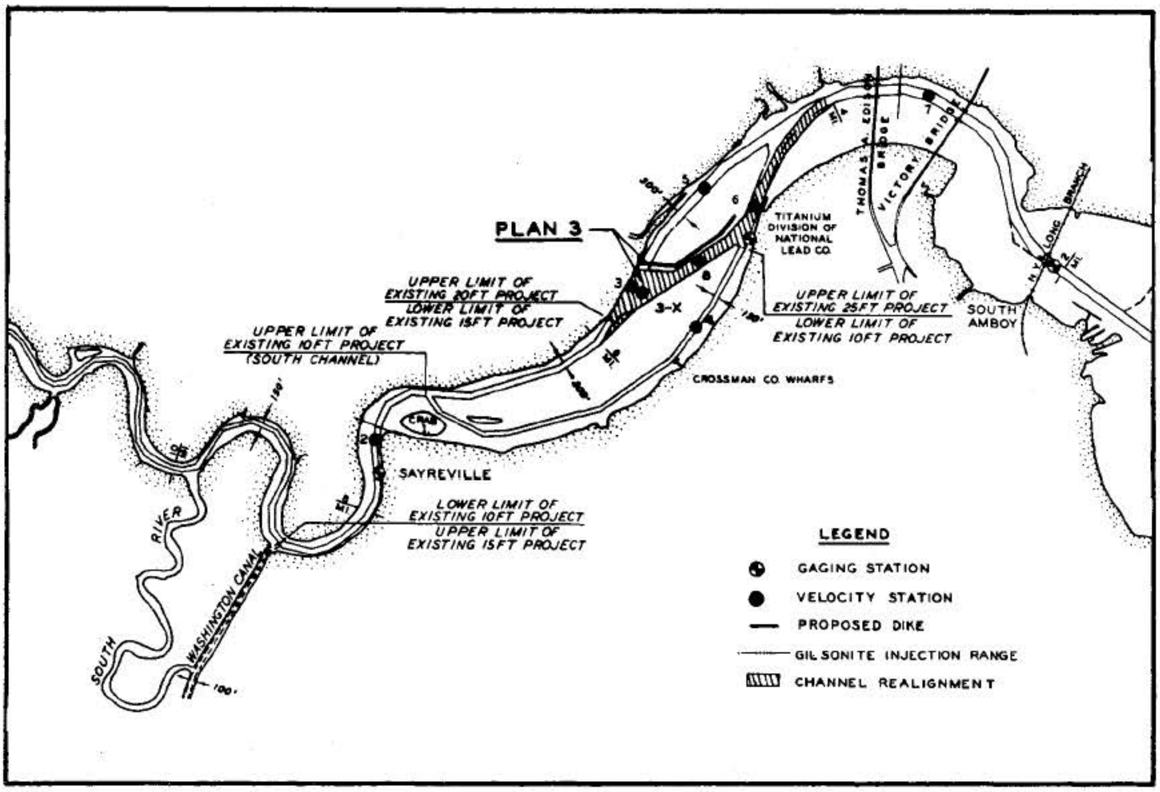


Fig. 5. Elements of plan 3

The plan consisted of a cutoff channel 20 ft deep and 300 ft wide extending from the turning basin at Raritan Arsenal to the upper end of the 25-ft project in south channel adjacent to the Titanium Division of the National Lead Company, together with a dike on the downstream side of the cutoff channel extending from the north shore to the intersection of the cutoff with south channel. Velocities at stations 3 and 5 were rendered of no significance by this plan, and alternate stations 3-X and 8 were established in the relocated channel (see fig. 5).

33. Results. The results of the hydraulic test of plan 3 are summarized in tables 4 and 5. The tidal ranges at the three major stations (Titanium, Sayreville, and New Brunswick) were increased slightly. Current velocities at stations 3-X, 4, 6, and 8 show the distribution of

flow through main and south channels, and those at stations 2 and 7 indicate the total flow of the river. Peaks of both ebb and flood velocities at station 7 were slightly increased; at station 2 the opposite was the case, the peaks of both ebb and flood velocities being slightly decreased. Average flood and ebb velocities at these stations, however, remained relatively unchanged, indicating that the plan did not change appreciably the total amount of water moving in and out with the tide. Flood velocities at station 4 were increased after the first half-hour of flood, and ebb velocities were reduced during the first three hours of ebb. The times of both high- and low-water slacks were retarded by approximately 0.25 hr. Only sufficient water to fill the local prism downstream from the dike protecting the relocated channel entered the lower end of the main channel, and no current-velocity measurements could be made at station 5. The entire tidal flow was forced to pass station 6 by the diking of the cutoff channel, and both ebb and flood velocities at this station were thereby increased considerably. The peaks of ebb and flood velocities at stations 6 and 8 were approximately the same; however, both ebb and flood velocities at station 8 leveled off earlier than those at station 6 because of the diversion of water into the upper end of south channel, as indicated by velocities measured at station 4. General flow conditions resulting from the installation of the plan were satisfactory; however, the flare at the upper end of the cutoff channel caused local reductions in velocities (compare stations 8 and 3-X) and considerable eddying in and adjacent to the Raritan Arsenal turning basin. The results of the shoaling test of plan 3 are presented in table 3.

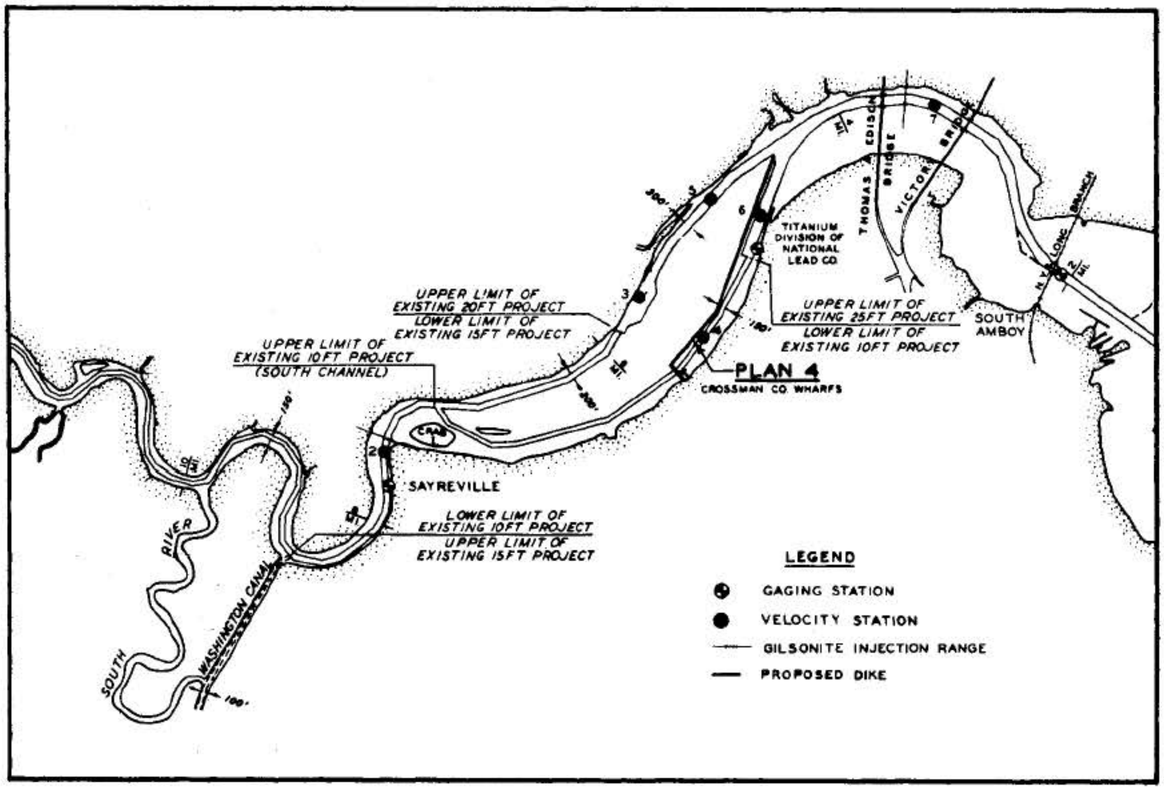


Fig. 6. Elements of plan 4

Plan 4

34. Description. The elements of plan 4 may be seen on fig. 6. The plan consisted of a dike extending parallel to south channel from a point slightly upstream from the lower intersection of south and main channels to a point slightly above the wharf of the Crossman Company, and thence directly across south channel to the south shore.

35. Results. The results of the hydraulic testing of plan 4 may be seen in tables 4 and 5. No significant changes occurred in tidal ranges at the three major gaging stations; however, the phasing of the tide at Sayreville was slightly retarded. This is considered attributable to the fact that the dike across south channel at the Crossman Company Wharf caused that portion of the tidal prism consisting of the upper end

of south channel and the adjacent bar area to fill and empty through the upstream intersection of south and main channels below Crab Island. This situation was reflected also in the current velocity measurements at station 2, where the flood peak of 1.25 ft per sec came at hour 5.5 as compared with the base-test flood peak of 1.45 ft per sec, which came at hour 4.5. The ebb peaks in both cases came at hour 10.00, but the plan effected a subsequent increase over base-test velocities of as much as 0.30 ft per sec. Average ebb and flood velocities at stations 2 and 7 did not indicate any considerable change in the tidal prism. Stations 3 and 5 both indicated increases in ebb and flood velocities over those of the base test, because of the tidal prism of the upper river and the prism of south channel above the Crossman Company Wharf passing through that reach of the main channel. Velocity measurements could not be made at stations 4 and 6 owing to the reduced flow caused by the dike. In the base test, water entering south channel during the early part of the flood tide was mostly bottom water, more easily diverted because of its lesser inertia; whereas the plan-4 dike, extending to a point just above the intersection of the two channels, also diverted into south channel the top water which had previously flowed across the bar and into the main channel. The results of the shoaling test of plan 4 are summarized in table 3.

Plan 5

36. Description. The elements of plan 5 may be seen on fig. 7. The plan consisted of a dike completely enclosing the bar which separates main and south channels.

37. Results. Plan 5 had no appreciable effect on tidal ranges or

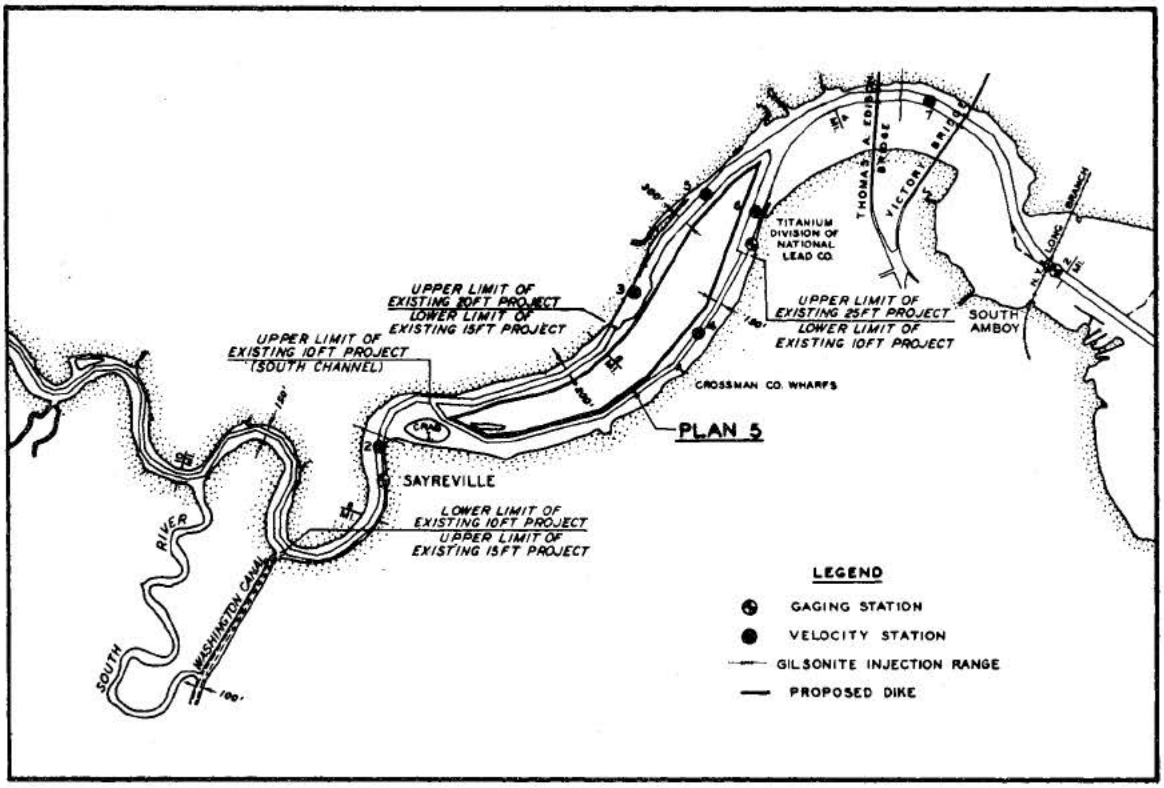


Fig. 7. Elements of plan 5

times of tidal events throughout the river. Both flood and ebb current velocities were reduced slightly at stations 2 and 7; the reductions at station 7 were of slightly greater magnitude than at station 2. This condition was probably the result of elimination of tidal fluctuation in the bar area enclosed by plan 5. Current-velocity measurements at stations 3, 4, 5, and 6 indicate that the dike affected the distribution of ebb and flood flow in main and south channels. Flood velocities were increased at stations 3 and 5 in main channel, while ebb velocities were decreased at station 3 and increased at station 5. Flood velocities were decreased at stations 4 and 6 in south channel, and ebb velocities were increased. The results of the shoaling test of plan 5 are presented in table 3.

Second Series (after New Prototype Survey)

38. The second series of tests was undertaken after completion of the new prototype survey and revision of the shoaling technique as outlined in Part III. Shoaling tests of plans 3, 4, and 5 were rerun for the revised shoaling adjustment, and plans 6, 3A, 3B, 3C, and 3D were added to the testing program. No hydraulic data are presented for plans 3, 4, and 5 for the second series of tests since these data have been presented previously.

Plan 3

39. Results. The results of the test of plan 3 are presented in table 6. Shoaling in sections 1 and 2 was decreased by 46 per cent and 73 per cent, respectively. Sections 3 and 4 were eliminated from the navigation channel by features of the plan; however, shoaling therein was decreased by 16 per cent. Shoaling in section 5 was increased by 12 per cent. Shoaling in sections 6 and 7, added to the navigation channel by the features of plan 3, amounted to 320 cc and 1070 cc respectively (no comparison to base-test shoaling could be made for sections 6 and 7 since they did not exist under basic conditions). The plan caused a 15 per cent increase in shoaling downstream from Edison Bridge. The over-all shoaling index for plan 3 (sections 1, 2, 5, 6, and 7 for plan 3 compared to sections 1, 2, 3, 4, and 5 for the base test) was 0.51, indicating that the plan would decrease shoaling in the problem area by approximately 49 per cent.

Plan 4

40. Results. The results of the test of plan 4 are also presented

in table 6. Shoaling in section 1 was decreased by 3 per cent, and in section 2 by 60 per cent. Shoaling in sections 3, 4, and 5 was decreased by 92 per cent, 31 per cent, and 7 per cent, respectively. Shoaling downstream from Edison Bridge was increased by 34 per cent. The over-all shoaling index for plan 4 was 0.50, indicating that the plan would decrease shoaling in the problem area by approximately 50 per cent.

Plan 5

41. Results. The results of the test of plan 5 are presented in table 6. Shoaling in section 1 was increased by 77 per cent. Shoaling in sections 2, 3, 4, and 5 was decreased by 40 per cent, 30 per cent, 12 per cent, and 24 per cent, respectively. Shoaling below Edison Bridge was increased by 56 per cent. The over-all shoaling index for plan 5 was 0.86, indicating that the plan would reduce shoaling in the problem area by approximately 14 per cent.

Plan 6

42. Description. The elements of plan 6 are shown on fig. 8. The plan consisted of a cutoff through Great Bend 500 ft wide and 15 ft deep, and a diversion dike across the upper end of the intercepted reach. The channel branched just above Crab Island, the south channel being 350 ft wide and 12 ft deep to the upper end of the 25-ft project in south channel. The north channel was 200 ft wide and 15 ft deep for a distance of 3000 ft to where it joined the existing 15-ft project.

43. Results. The results of the hydraulic test of plan 6 are presented in tables 4 and 5; the results of the shoaling test are presented in table 6. The tidal range at New Brunswick was increased 0.2 ft, this difference occurring at high water. There were no differences in the

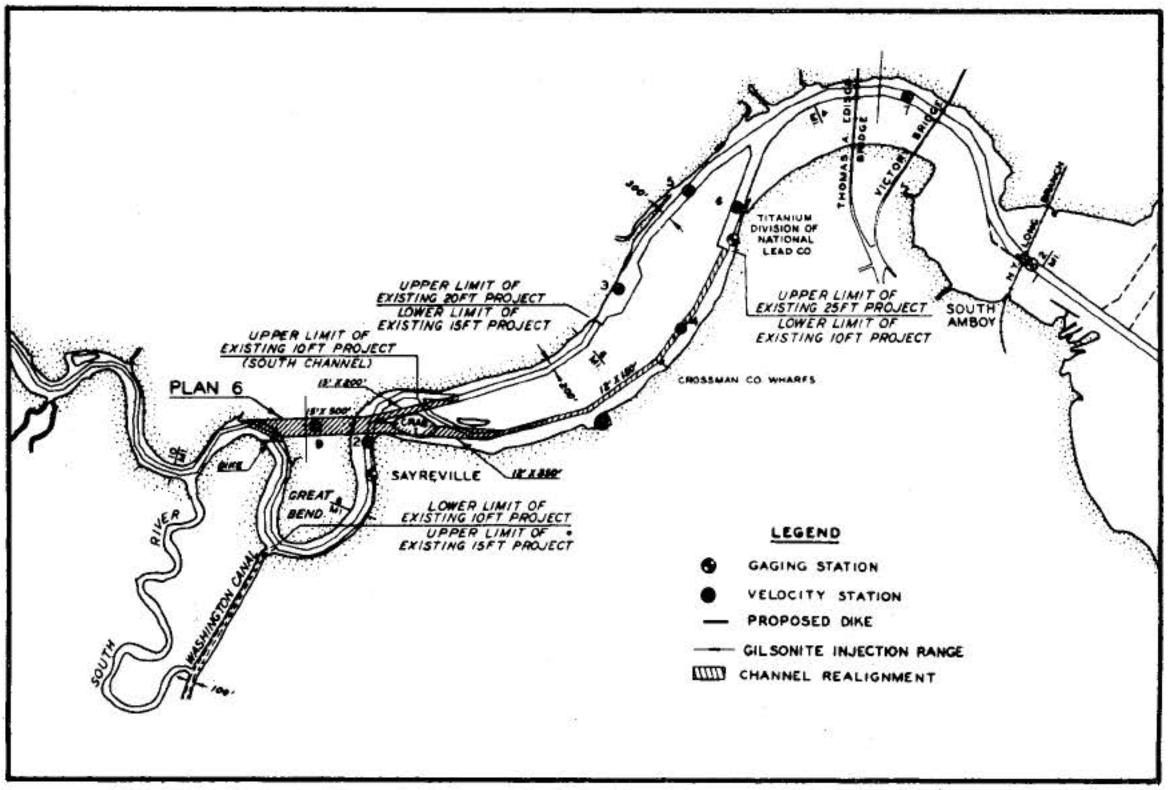


Fig. 8. Elements of plan 6

times of high and low waters. The tidal range at Sayreville, in the intercepted reach of the river, was reduced by 0.05 ft, this difference occurring at high water. At the Titanium gage the total range was reduced by 0.1 ft, this being split between high and low waters. No changes occurred in the times of high and low waters. Current velocities at station 7 were slightly reduced during ebb tide, while the flood velocities were generally unchanged. Both ebb and flood velocities were reduced at stations 5 and 6. Strength of flood at station 4 occurred about 0.25 hour later than in the base test. Ebb and flood velocities were reduced slightly at station 3. Shoaling in section 1 was reduced by 44 per cent, while that in section 2 was not changed by the plan. Shoaling in section 3 was reduced by 16 per cent, while that in sections 4 and 5 was increased

by 18 per cent and 11 per cent, respectively. Shoaling downstream from Edison Bridge was reduced by 54 per cent. Little shoaling occurred in main channel upstream from the turning basin at Raritan Arsenal, or in the 500-ft-wide cutoff; however, the 350-ft-wide channel through Crab Island shoaled about 3 ft over its entire length. The over-all shoaling index for plan 6 was 0.91, indicating that the plan would probably reduce shoaling in the problem area (sections 1, 2, 3, 4, and 5) by approximately 9 per cent.

Plan 3A

44. Description. The elements of plan 3A are shown on fig. 9. The plan consisted of relocation of the main 20-ft channel in the vicinity of the National Lead Company towards the south shore and the elimination of

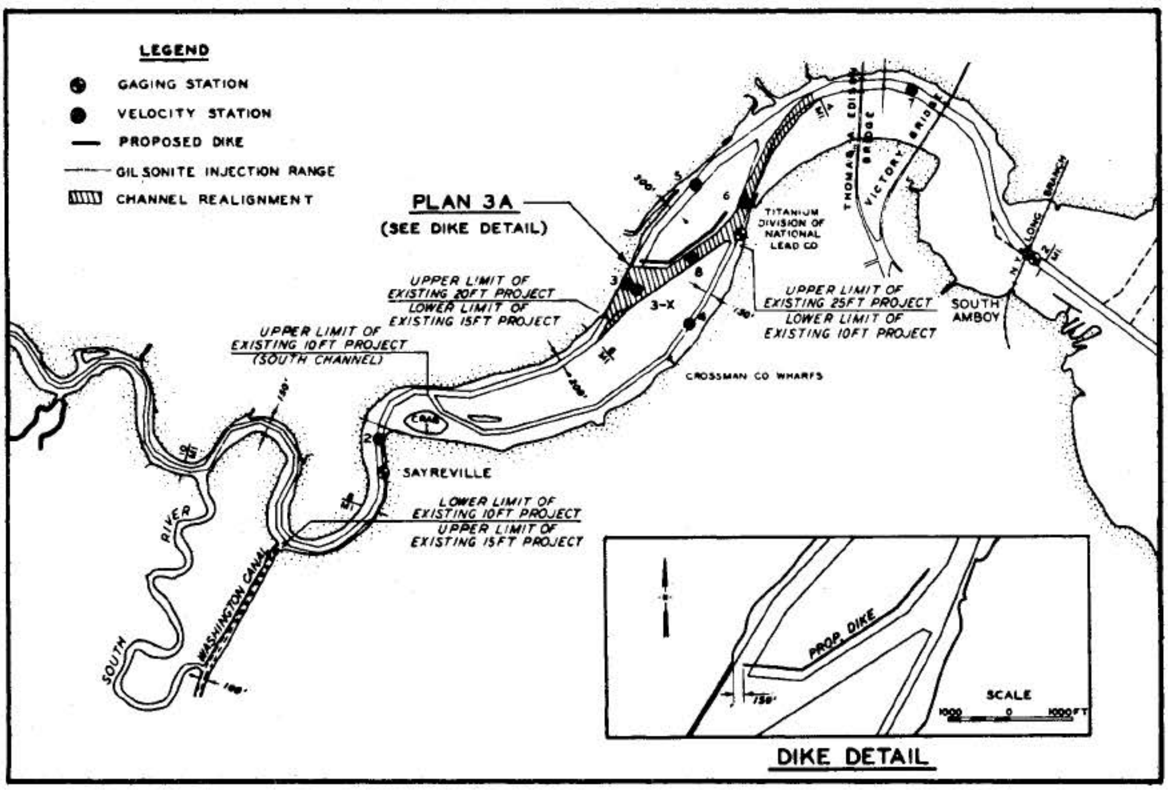


Fig. 9. Elements of plan 3A

the westerly 150 ft of the plan-3 dike to provide an opening for navigation purposes.

45. Results. The results of the hydraulic test of plan 3A are presented in tables 4 and 5. The plan had only very slight effects upon tidal heights throughout the waterway, the greatest being the raising of both high- and low-water planes upstream from the problem area. Current velocities at stations 2 and 7 were relatively unchanged. The maximum ebb velocity in the main channel below the dike was 0.60 ft per sec, and the maximum flood velocity was 0.48 ft per sec. This represents a considerable decrease from the base-test velocities, owing to the partial closure of the main channel, but a proportional increase resulted at station 6, indicating some diversion of flow through the relocated channel. The results of the shoaling test of plan 3A may be seen in table 7. Shoaling in section 1 was relatively unchanged by the plan, shoaling in section 2 was reduced by 57 per cent, and that in section 5 was reduced by 4 per cent. Shoaling in section 3 was reduced by 22 per cent, and that in section 4 was increased by 115 per cent. Shoaling downstream from section 1 was reduced by 42 per cent. The over-all plan index was 0.77, indicating a reduction in total shoaling of about 23 per cent.

Plan 3B

46. Description. The elements of plan 3B are shown on fig. 10. The plan consisted of relocation of the main 20-ft channel in the vicinity of the National Lead Company towards the south shore and modifications of the plan-3 dike as follows: elimination of the westerly 300 ft of the dike; and addition of a 1000-ft northerly extension of the dike, 250 ft east of the existing westerly channel line, with a closure dike extending

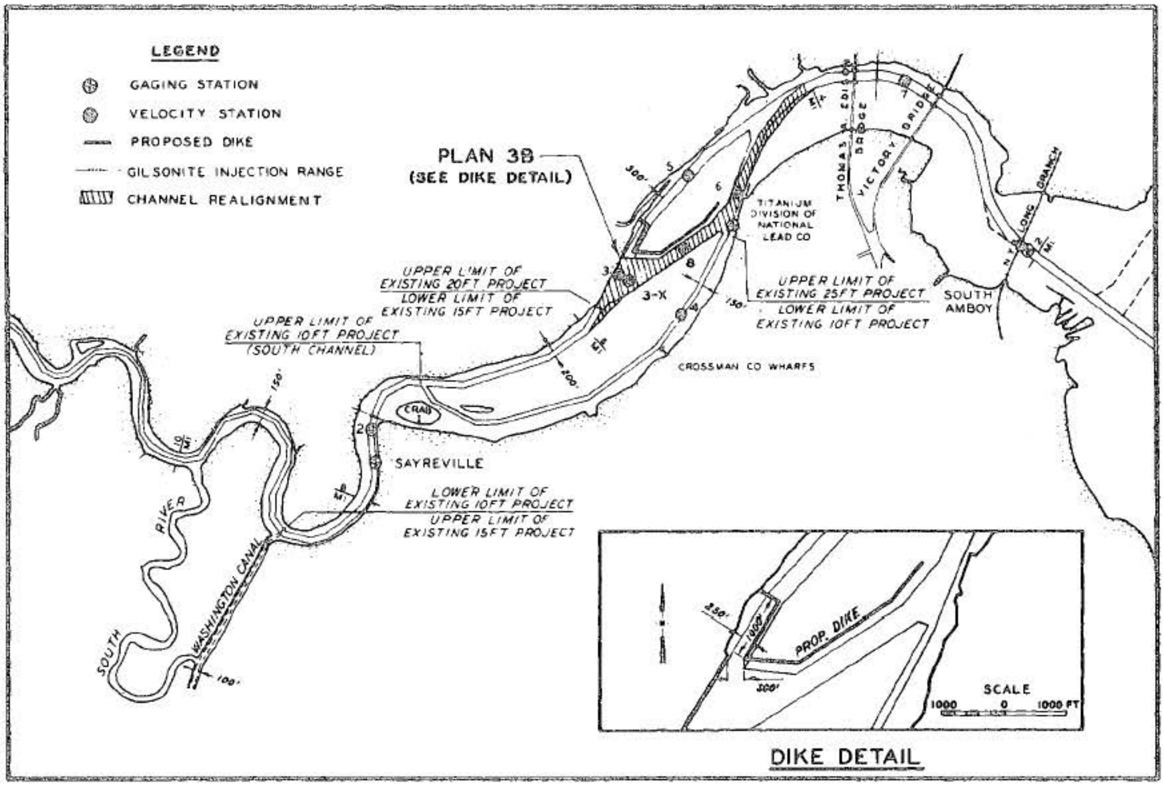


Fig. 10. Elements of plan 3B

from the northerly end of the extension to the west bank.

47. Results. The results of hydraulic tests of plan 3B are summarized in tables 4 and 5, and the results of the shoaling test are presented in table 7. There were no significant changes in tidal heights as a result of the plan. Current velocities at station 6 were more than doubled, while those at station 5 were too small to be measured as a result of the closure of the main channel by the plan dike. The plan caused a 12 per cent reduction in shoaling in section 1 and a 54 per cent reduction in section 2. Sections 3 and 4 showed reductions of 42 and 6 per cent, respectively. Shoaling in the turning basin, enlarged by the diked area, was increased by 72 per cent. Sections 6 and 7 shoaled less than for plan 3A. Shoaling downstream from section 1 was increased by

20 per cent. The over-all index for plan 3B was 0.77, indicating a reduction in total shoaling of about 23 per cent.

Plan 3C

48. Description. Plan 3C consisted of relocation of the main 20-ft channel in the vicinity of the National Lead Company towards the south shore and modifications of the plan-3 dike as follows: elimination of the westerly 300 ft of the dike to provide a navigation opening, and addition of a 1000-ft northerly extension 250 ft east of the existing westerly channel line. The elements of plan 3C may be seen on fig. 11.

49. Results. The results of hydraulic tests of plan 3C are summarized in tables 4 and 5, and the results of the shoaling test are presented in table 7. There were no significant changes in tidal heights

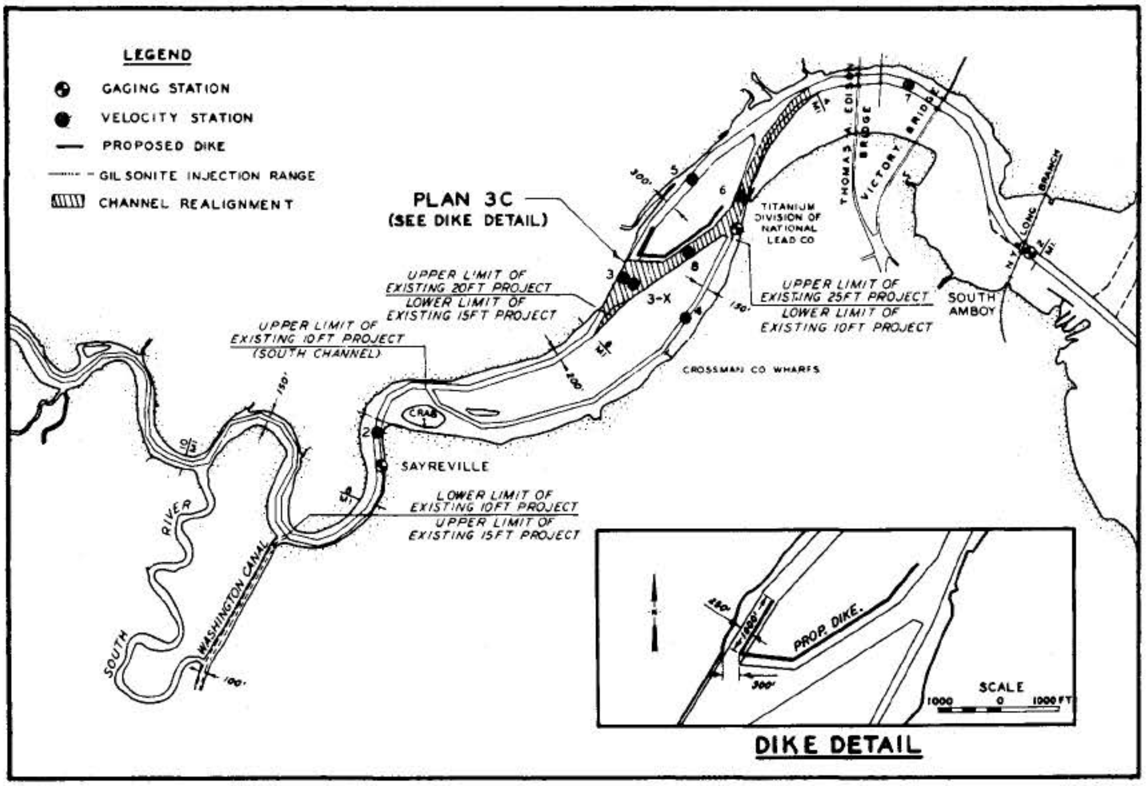


Fig. 11. Elements of plan 3C

throughout the harbor. Current velocities at station 5 were higher than those for plan 3A, indicating a greater diversion of flow from the realigned channel owing to the larger opening in the dike. Shoaling in section 1 was increased by 15 per cent, that in section 2 was reduced by 38 per cent, and that in section 5 was increased by 89 per cent. Sections 6 and 7 shoaled more than in the case of plans 3A and 3B. Sections 3 and 4 showed considerable increases in shoaling. Shoaling downstream from section 1 was reduced by 33 per cent. The over-all plan index was 1.05, indicating an increase in total shoaling of about 5 per cent.

Plan 3D

50. Description. The elements of plan 3D may be seen on fig. 12. The plan consisted of relocation of the main 20-ft channel in the vicinity

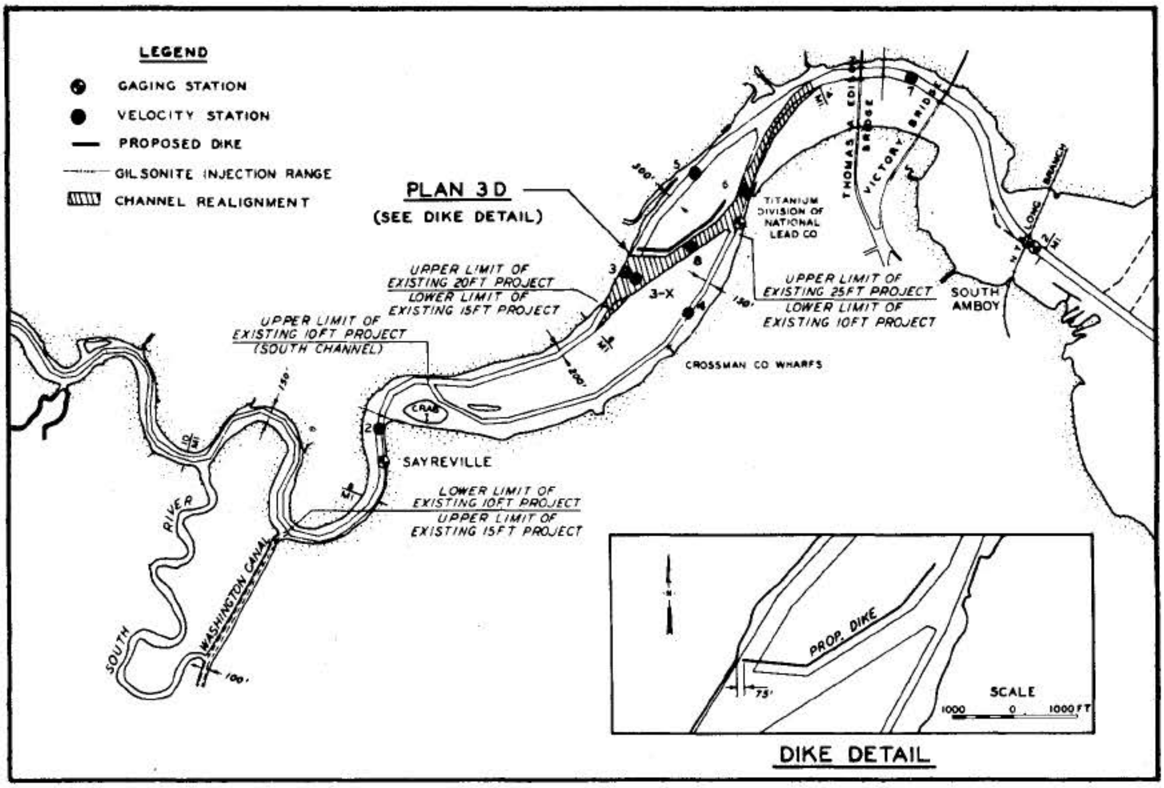


Fig. 12. Elements of plan 3D

of the National Lead Company towards the south shore and modification of the plan-3 dike by the elimination of its westerly 75 ft, leaving an opening for navigation purposes.

51. Results. The results of hydraulic tests of plan 3D are shown in tables 4 and 5, and the results of the shoaling test are summarized in table 7. No significant changes resulted in tidal heights throughout the river. Apparently, flow in main channel was less than for either plan 3A or 3C, since the velocities therein were somewhat less. Shoaling in section 1 was increased 34 per cent, that in section 2 was decreased 57 per cent, and that in section 5 was increased 68 per cent. Sections 6 and 7 experienced less shoaling than was the case with plan 3C. Section 3 showed a 35 per cent decrease in shoaling and section 4 a 60 per cent increase. The plan had no effect on shoaling downstream from section 1. The over-all shoaling index was 0.93, indicating a reduction in total shoaling of about 7 per cent.

Modified Plans

52. A conference with personnel of the North Atlantic Division, the New York District, and interested local agencies resulted in a decision to modify plans 3 and 3D, already tested, by eliminating the channel widening at the junction of south and main channels and that at the Raritan Arsenal (compare plate 3 and fig. 13) and to retest them for comparison with a new base test more nearly like the original one. In addition, plans 3E, 3F, 3G, and 3H were tested. All of these plans incorporated the plan-3 channels. Plan 3E consisted of shifting the main channel closure dike about 1000 ft downstream to provide additional

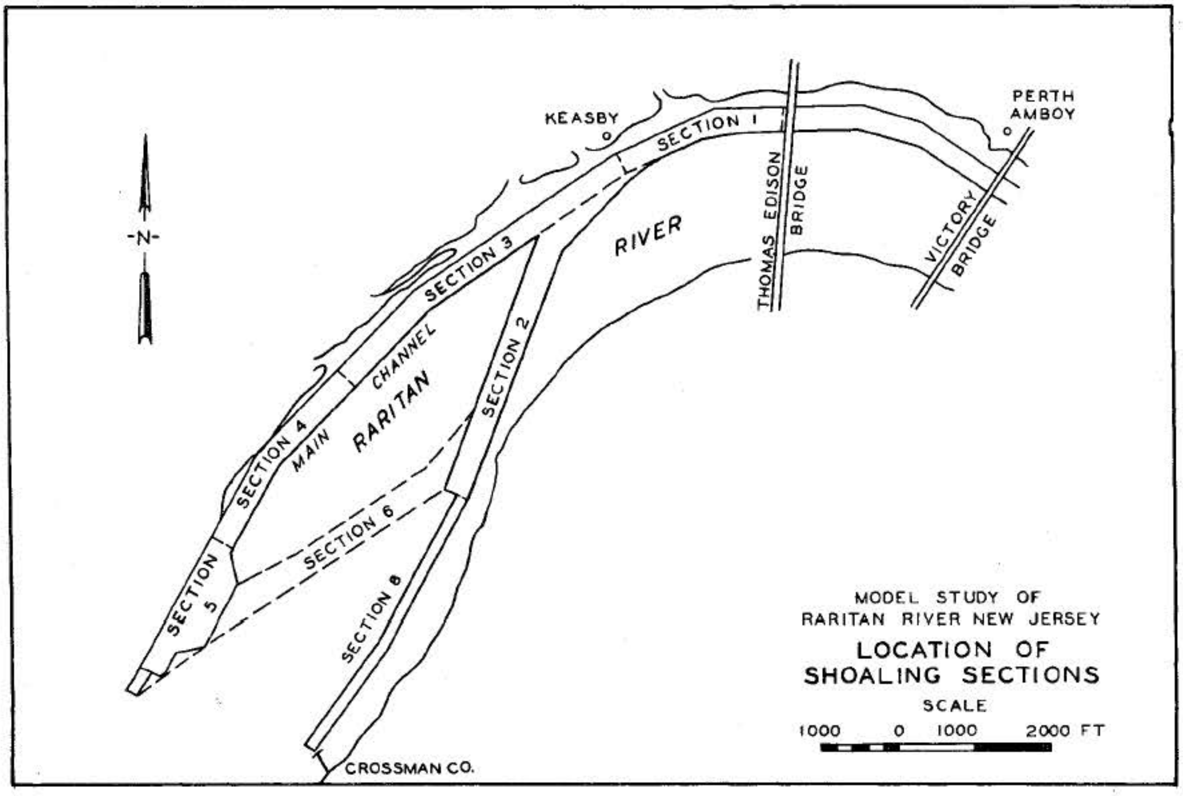


Fig. 13. Location of shoaling sections (modified plans)

anchorage area for Raritan Arsenal; the dike then crossed the bar separating main and south channels and turned parallel to the widening at the junction of south channel with the cutoff channel for a distance of about 800 ft. Plan 3F consisted of a closure of main channel about 1000 ft downstream from Raritan Arsenal, the closure dike connecting with the existing dike which runs parallel to the east side of main channel. Observations in the model indicated one or more undesirable characteristics of plans 3E and 3F; therefore, further testing of these plans was considered unnecessary.

53. Visual observation of the effects of plans 3G and 3H in the model led to the decision that they should be subjected to complete tests. These plans are described in detail on the following pages.

Plan 3 modified

54. Description. Plan 3 modified consisted of the original plan 3, described in paragraph 32, with plan-3 channel widenings eliminated at the downstream junction of south and main channels and at the Raritan Arsenal turning basin. The elements of plan 3 modified are shown on fig. 14.

55. Results. No hydraulic data were obtained for modified plan 3, because of its similarity to the original plan 3, for which complete hydraulic data were obtained. The results of the shoaling test may be seen in table 8. Shoaling in section 1 was decreased by 30 per cent, and that in section 2 by 43 per cent. Shoaling in section 5 was increased by 80 per cent, and that in section 8 (10-ft channel to Crossman's Wharf) by 87 per cent. Shoaling in the relocated channel (section 6) amounted to 458 cc

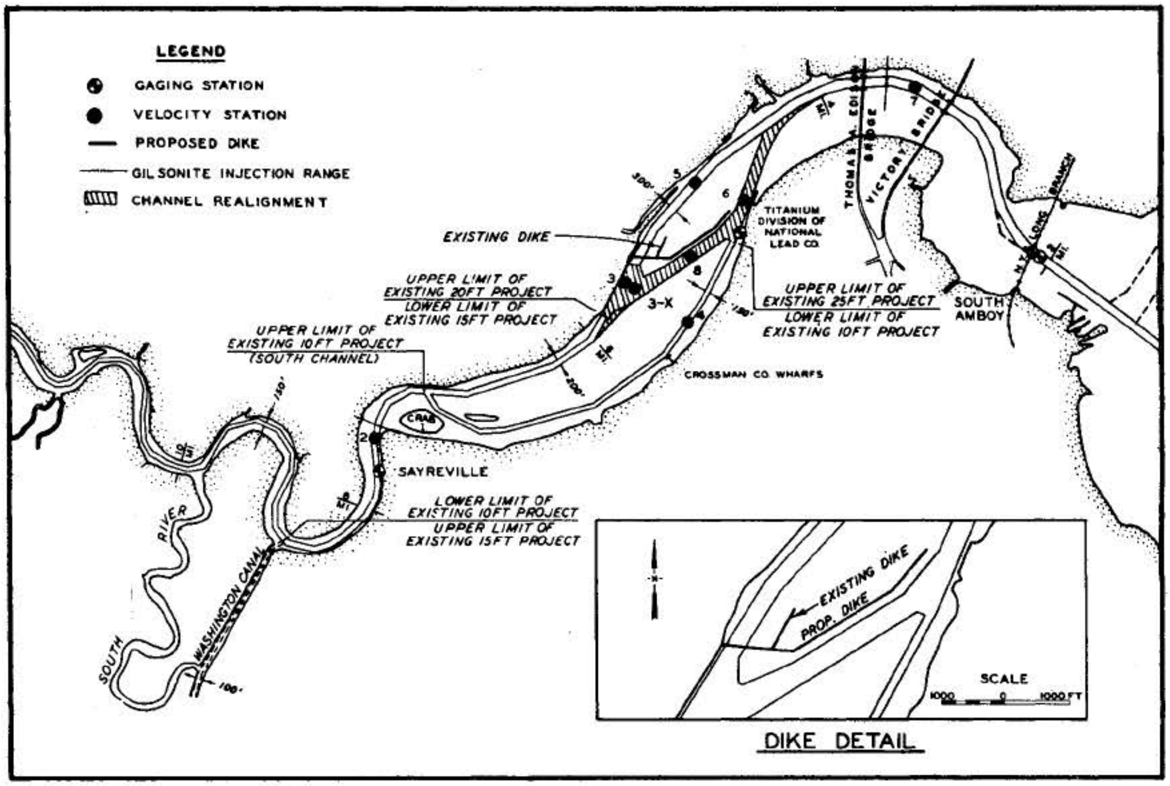


Fig. 14. Elements of plan 3 modified

or slightly less than shoaling in section 5 for the base test. The plan index was 0.62, indicating that maintenance dredging in the problem area would be reduced about 38 per cent. Shoaling downstream from the problem area was increased by 62 per cent, indicating that most of the material eliminated from the problem area by the plan was shifted downstream. The shoaling pattern at the end of the test is shown on plate 6.

Plan 3D modified

56. Description. Plan 3D modified (fig. 15) was identical with plan 3D except for the elimination of the channel widenings at the junction of south and main channels and at Raritan Arsenal.

57. Results. The results of the shoaling test of plan 3D modified may be seen in table 8. The only hydraulic data obtained were current

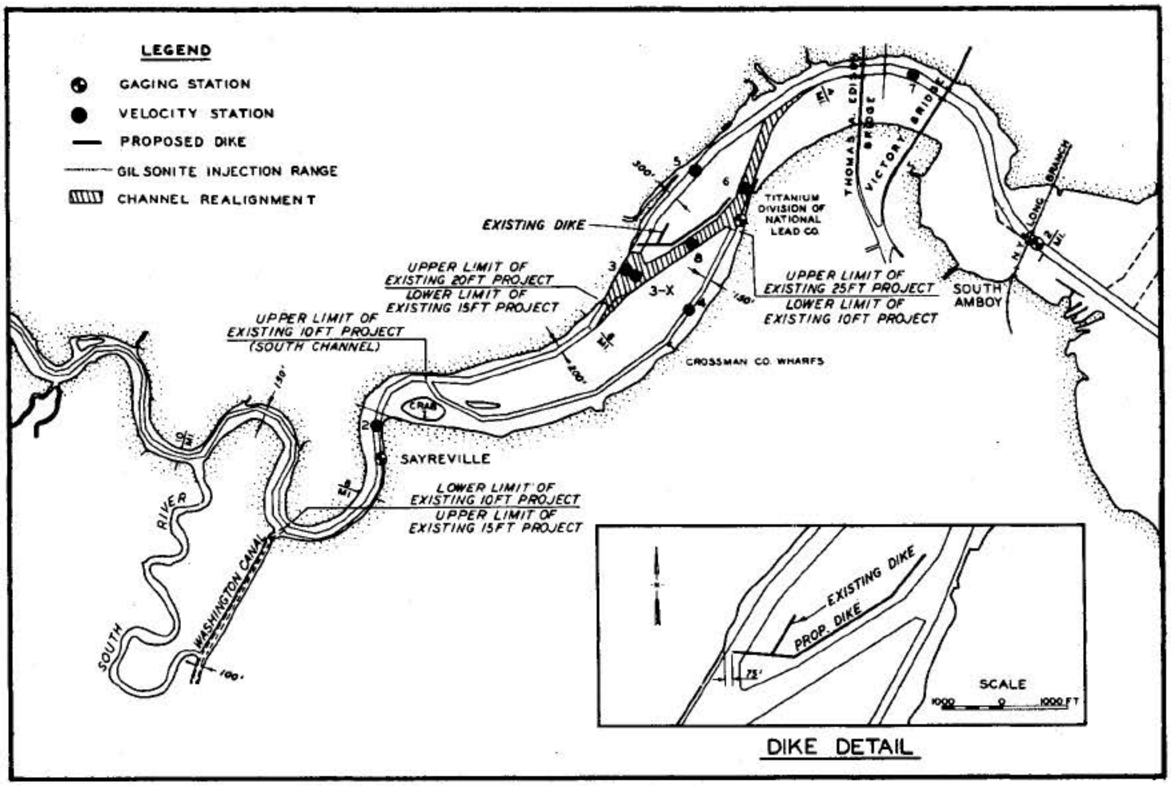


Fig. 15. Elements of plan 3D modified

velocities in the dike navigation opening. The maximum ebb current velocity in the opening was 1.9 ft per sec and the maximum flood was 1.7 ft per sec. Shoaling in section 5 was increased by 56 per cent, and that in section 8 was increased by 124 per cent. Shoaling in the relocated channel (section 6) was approximately three times as great as for plan 3. The plan index was 0.80, indicating that shoaling in the problem area would be reduced about 20 per cent. Shoaling downstream from the problem area was increased by 12 per cent, indicating that most of the material removed from that area by the plan was shifted downstream. Plate 6 shows the shoaling pattern at the end of the test.

Plan 3G

58. Description. Plan 3G (fig. 16) was identical to modified plan

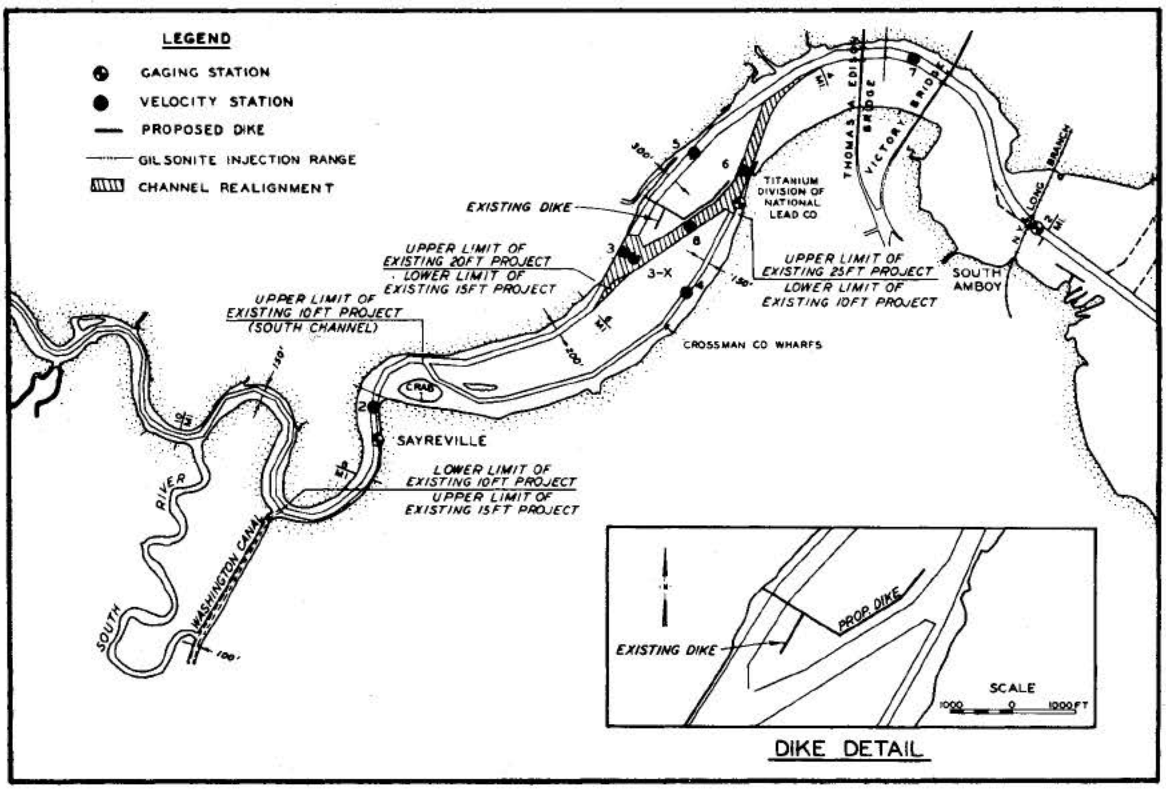


Fig. 16. Elements of plan 3G

3 except that the main channel closure dike was moved downstream approximately 1000 ft to provide additional anchorage area for Raritan Arsenal.

59. Results. The results of the shoaling test of plan 3G are shown in table 8. No hydraulic data were obtained because of the similarity of plan 3G to plan 3. Shoaling in section 1 was not affected, while that in section 2 was reduced by 55 per cent. Shoaling in section 5 was increased by 93 per cent, and that in section 8 by 166 per cent. Shoaling in the relocated channel (section 6) was about two-and-one-half times that of modified plan 3. The plan index was 0.73, indicating that shoaling throughout the problem area would be reduced by about 27 per cent. Shoaling downstream from the problem area was not affected by the plan. The shoaling pattern at the end of the test is shown on plate 8.

Plan 3H

60. Description. The channels of plan 3H (fig. 17) were identical to those of modified plan 3; however, the plan-3H dike completely closed main channel just above the junction of south and main channels and paralleled south channel to a point opposite the upstream limit of the present 25-ft channel.

61. Results. The results of the shoaling test of plan 3H are shown in table 8. Observations of tidal heights and current velocities for the plan are shown in tables 4 and 5. Shoaling in section 1 was reduced by 29 per cent, and that in section 2 was reduced by 72 per cent. Shoaling in section 5 was increased by 118 per cent, and that in section 8 was increased by 161 per cent. The plan index was 0.53, indicating that shoaling throughout the problem area would be reduced about 47 per cent. Shoaling downstream from the problem area was increased by 67 per cent,

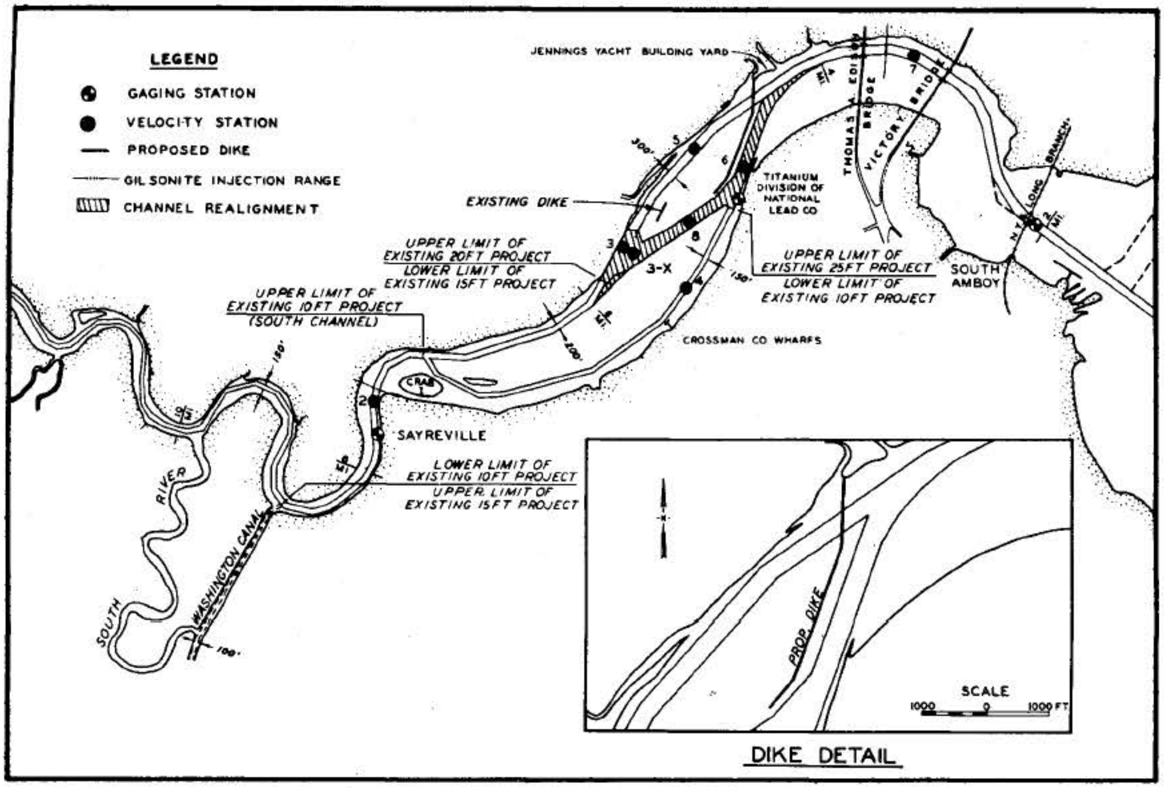


Fig. 17. Elements of plan 3H

indicating that most of the material removed from the problem area by the plan was shifted downstream. Shoaling in the relocated channel (section 6) was slightly greater than for modified plan 3. The shoaling pattern at the end of the test is shown on plate 9. Current velocities at station 6 were increased appreciably from the base condition (table 5), while velocities at station 8 were higher than for the other modified plans. Tidal heights throughout the river were relatively unaffected.

62. Effect of plan 3H on floods. The orientation of the plan-3H dike was such that it would probably offer some resistance to the passage of floods unless provision were made to pass some of the water over the dike. Therefore, the plan was tested for its effect upon the water-surface profiles for a discharge of 39,200 cfs (the greatest discharge that could be

confined to the model channel in the upstream reaches) and with the top elevation of the dike at mhw. The high- and low-water profiles from Landing Bridge to the Titanium gage, with and without plan 3H installed, are shown on plate 10. The profiles for plan 3H with a mean fresh-water discharge are also shown. The dike raised high water by 0.2 ft and 0.1 ft, respectively, at the New Brunswick and Sayreville gages, and lowered high water by 0.2 ft and 0.15 ft, respectively, at Raritan Arsenal and Titanium. Low-water elevations were raised 0.4 ft at New Brunswick, 0.1 ft at Sayreville, 0.1 ft at the Arsenal, and 0.1 ft at Titanium. It therefore appears that plan 3H would have little effect on passage of a flood through the harbor, provided that the top elevation of the dike is not greater than mhw.

Drift tests

63. Purpose. Information was desired as to the progressive rate of seaward drift in the lower river for low, medium, and high fresh-water flows. The rate of drift was determined by observing the downstream and upstream movement of a pole float during ebbing and flooding tides. The float was weighted so that 16.0 ft of it was submerged. Tests were made with flows of 100, 1500, and 8,000 cfs.

64. 100-cfs discharge. The results of the 100-cfs test may be seen on plate 12, which also shows a plot of the mean tide curve at South Amboy gage. Distances above mile 0 in intervals of 0.2 mile are shown on plate 11. The float was placed in the river at mile 4.35 at high-water slack. It moved down to mile 0.65 with the first ebb, and thence back to mile 3.72 with the subsequent flood. The succeeding ebb moved it into the head bay. The net seaward movement during the interval between high waters was 0.63 miles.

65. <u>1500-cfs discharge.</u> The results of the 1500-cfs test may be seen on plate 12. The float was placed in the model at mile 4.5 at high-water slack. With the ebb it moved to mile 0.4, and thence to mile 3.44 with the flood. It moved into the head bay with the ensuing ebb. The seaward drift was 1.06 miles.

66. <u>8,000-cfs discharge.</u> The results of the 8,000-cfs test may be seen on plate 12. The float was placed in the channel at mile 5.4 at high-water slack. It moved to mile 0.47 with the following ebb, and thence to mile 2.15 with the flood. With the ensuing ebb it moved into the head bay. The seaward drift was 3.25 miles.

<u>Discussion of results</u>

67. The rate of seaward drift of the pole float in miles per tidal cycle, plotted against fresh-water discharge, is shown on the insert on plate 12. The results of the drift tests do not represent the seaward drift of a theoretical slug of water, comprising the entire cross section of the river, but only that of a float in the navigation channel. Theoretically, a given slug of water, oscillating in the tidal reach of the river, would never reach the ocean if the fresh-water discharge were zero and flow throughout the cross section were uniform. It would be expected, therefore, that the rate of rise of the seaward drift curve (plate 12) would be very gradual near zero fresh-water discharge, and would accelerate with increasing discharge. The float curve, however, never approaches 0 miles of drift, even for 100-cfs discharge. These tests are not entirely comparable, since the 8,000-cfs discharge caused such rapid downstream movement that the float had to be moved to a point upstream from the turning basin to prevent its entering the head bay with the first ebb.

PART V: LIMITATIONS AND ACCURACY

Hydraulic Tests

68. The accuracy of hydraulic data obtained from the model may be relied upon quantitatively except for certain minor limitations. These limitations are imposed by termination of the model in Raritan Bay, which affects to some extent the results of the drift tests; and construction of the upstream reaches of the model to a constant overbank elevation of +18 ft, which may have affected the accuracy of results of the flood tests. However, this latter limitation is believed to be of little significance since the results of the flood tests were evaluated on a comparative basis. All hydraulic data obtained for mean fresh-water flow conditions are considered reliable and can be transferred to the prototype in a quantitative manner.

Shoaling Tests

69. The results of model shoaling tests cannot be transferred quantitatively to the prototype; therefore, model shoaling data must be evaluated on a comparative or qualitative basis. The limitation on transference of model shoaling data is brought about by the following factors: (a) the model did not reproduce in-place flocculation of suspended sediment, which probably accounts for a high rate of shoaling in some areas of the prototype; (b) the effects of ship traffic on shoaling were not taken into consideration; and (c) there is no assurance that the relationship between prototype current velocity and the deposit or scour of prototype shoaling material was reproduced to scale in the model.

70. It is believed, however, that when the model is adjusted to reproduce accurately the percentile distribution of prototype shoaling, as was the Raritan River model, the effects of a proposed improvement plan on the distribution of shoaling material will be reflected with reasonable accuracy. Also, the effectiveness of the various improvement plans on a comparative basis should be reflected with a high degree of accuracy.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

71. One of the chief causes of shoaling in the Raritan River appears to be channel bifurcation, which results in insufficient current velocities to prevent shoaling in either channel. Also, the present location and alignment of south channel is such that flood-tide currents into this channel are fed from the lower strata of the channel which contain a large proportion of the suspended sediment load and all of the bed load. All of the various modifications to plan 3 substitute one channel for the existing two channels and thus eliminate the bifurcation. The original plan 3, however, provided for a closure of main channel immediately downstream from Raritan Arsenal, thus denying anchorage facilities to the arsenal. Plan 3H appears to be the most beneficial of all of the various modifications to plan 3 tested in the model.

72. The prototype study indicated that the immediate source of some of the material shoaling south channel is downstream from the problem area. Furthermore, all material in suspension in the river which does not settle on some shoal must eventually pass and repass that portion of the main channel below its junction with south channel; yet this channel does not experience shoaling. The reason appears to be either that the current velocities are strong enough to keep the material in suspension, or they are strong enough at times (whether on ebb or flood) to scour deposited material and place it in suspension again. The orientation of the plan-3H dike took advantage of the initially high flood velocity to place settled material in suspension. The resulting effect was creation of a situation in the problem area similar to that in the

main channel below the junction. At the same time, however, shoaling in the Raritan Arsenal turning basin, which was increased by all of the plan-3 realignments, was increased more by plan 3H than by any of the other plan-3 alignments. Most of the shoaling in main channel above the junction now occurs in the turning basin, where the widened cross section necessary for a turning basin tends to invite shoaling. It is doubtful whether any improvement plan not eliminating the Raritan Arsenal turning basin could prevent heavy shoaling there. It is to be expected, then, not only that maintenance dredging will continue to be required in the turning basin, but that it will probably have to be increased there for any of the plan-3 realignments.

73. On the basis of the above conclusions, plan 3H is recommended for construction in the prototype with the crest elevation of the dike at mean high water.

TABLES

Table 1

VERIFICATION OF TIDAL HEIGHTS

	Time of High Water	Elev of High Water	Time of Low Water	Elev of Low Water	Range of Tide
	Titanium Gaging Station, 3 Oct 1947, 182 cfs River Flow				
Prototype	7.98	5.01	2.00	0.01	5.00
Model	8.00	5.10	2.00	0.00	5.10
	Sayreville Gaging Station, 3 Oct 1947, 182 cfs River Flow				
Prototype	7.98	5.25	2.06	-0.05	5.30
Model	8.00	5.20	2.00	-0.10	5.30
	South River Gaging Station, 14 Dec 1947, 455 cfs River Flow				
Prototype	7.81	5.21	2.13	-0.09	5.30
Model	8.50	5.35	2.50	0.00	5.35
	New Brunswick Gaging Station, 3 Oct 1947, 182 cfs River Flow				
Prototype	8.62	5.40	2.48	-0.30	5.70
Model	8.50	5.45	3.00	-0.20	5.65
	Landing Bridge Gaging Station, 11 Dec 1947, 601 cfs River Flow				
Prototype	8.58	5.60	2.63	2.90	2.70
Model	9.00	5.80	3.00	3.10	2.70

Notes: Time is in hours after moon's transit of South Amboy meridian.
Elevations refer to mlw at South Amboy.

Table 2

VERIFICATION OF CURRENT VELOCITIES OF 22 AUGUST 1947

Fresh-water Discharge, 973 Cfs

Station No.	Prototype or Model	Maximum Velocity Ft/Sec	Average Velocity Ft/Sec	Time* of Slack
		Flood Tide		
2	Prototype	1.79	0.89	8.70
	Model	1.77	0.84	8.25
3	Prototype	1.28	0.79	9.20
	Model	1.30	0.71	8.50
4	Prototype	0.92	0.54	7.80
	Model	2.17	0.96	8.00
5	Prototype	1.19	0.61	9.25
	Model	1.47	0.80	8.20
6	Prototype	1.03	0.68	8.90
	Model	0.86	0.54	8.00
7	Prototype	1.72	1.04	8.70
	Model	1.64	0.94	8.00
		Ebb Tide		
2	Prototype	2.18	1.08	2.65
	Model	1.72	1.08	2.60
3	Prototype	1.62	0.94	2.55
	Model	1.25	0.86	2.50
4	Prototype	1.20	0.43	2.75
	Model	1.09	0.70	2.25
5	Prototype	1.59	0.86	2.85
	Model	1.47	1.01	2.75
6	Prototype	1.09	0.72	3.00
	Model	0.85	0.53	2.50
7	Prototype	1.81	0.94	3.20
	Model	1.38	0.93	2.25

* Time in hours after moon's transit of South Amboy meridian.

Table 3

MODEL SHOALING IN FIRST SERIES OF TESTS

Test	Material Injected Cu Cm	Material Recovered by Sections* in Cu Cm and Shoaling Indices														Total Material Recovered	
		Section 1		Section 2		Section 3		Section 4		Section 5		Section 6		Section 7			
		Mate-rial	Index	Mate-rial	Index	Mate-rial	Index	Mate-rial	Index	Mate-rial	Index	Mate-rial	Index	Mate-rial	Index	Cu Cm	Plan Index
Base	16,000	930		2170		1610		1090		2790						8,590	
Plan 3	16,000	930	1.00	1240	0.57	----	----	----	----	5580	2.00	2480	----	1180	----	11,410	1.33
Plan 4	16,000	1860	2.00	990	0.46	870	0.54	930	0.85	2640	0.95					7,290	0.85
Plan 5	16,000	1395	1.50	1240	0.57	2015	1.25	1240	1.14	3875	1.39					9,765	1.14

* Section locations shown on plate 3.

Table 4

TIDAL HEIGHTS IN FEET (PROTOTYPE)

	Location of Gaging Station								
	Titanium Gage			Sayreville Gage			New Brunswick Gage		
Test	Elev of High Water	Elev of Low Water	Tidal Range	Elev of High Water	Elev of Low Water	Tidal Range	Elev of High Water	Elev of Low Water	Tidal Range
Base Test	5.25	-0.05	5.30	5.25	-0.05	5.30	5.50	0.00	5.50
Plan 3	5.25	-0.15	5.40	5.40	0.00	5.40	5.70	0.00	5.70
Plan 3A	5.20	-0.05	5.25	5.35	0.05	5.30	5.60	-0.10	5.70
Plan 3B	5.20	-0.10	5.30	5.30	0.05	5.25	5.50	-0.15	5.65
Plan 3C	5.25	0.00	5.25	5.35	0.05	5.30	5.65	-0.05	5.70
Plan 3D	5.25	-0.05	5.30	5.25	-0.05	5.30	5.55	-0.10	5.65
Plan 3H	5.22	0.00	5.22	5.35	0.05	5.30	5.70	0.00	5.70
Plan 4	5.20	0.00	5.20	5.25	-0.05	5.30	5.55	0.00	5.55
Plan 5	5.25	-0.05	5.30	5.25	-0.05	5.30	5.50	0.00	5.50
Plan 6	5.20	0.00	5.20	5.20	-0.05	5.25	5.70	0.00	5.70

Note: Elevations refer to mlw at South Amboy.

Table 5

CURRENT VELOCITY IN FEET PER SECOND (PROTOTYPE)

Station No.	Direction of Flow	Base Test Max Veloc	Base Test Avg Veloc	Base Test Time of Slack	Plan 3 Max Veloc	Plan 3 Avg Veloc	Plan 3 Time of Slack	Plan 3A Max Veloc	Plan 3A Avg Veloc	Plan 3A Time of Slack	Plan 3B Max Veloc	Plan 3B Avg Veloc	Plan 3B Time of Slack	Plan 3C Max Veloc	Plan 3C Avg Veloc	Plan 3C Time of Slack
2	Ebb	2.20	1.40	2.75	2.15	1.45	2.75	2.17	1.36	2.70	2.04	1.39	2.80	2.42	1.42	2.70
	Flood	1.45	0.75	8.50	1.10	0.60	8.75	0.82	0.53	8.20	0.96	0.55	8.50	0.89	0.58	8.20
3	Ebb	1.50	1.00	2.50	----	----	----	0.68	0.41	2.00	----	----	----	0.47	0.32	2.60
	Flood	1.35	0.80	8.50	----	----	----	0.88	0.56	8.00	----	----	----	1.28	0.72	8.60
3X	Ebb	----	----	----	1.75	1.10	2.75	1.66	1.09	2.75	1.72	1.03	2.80	1.88	1.08	3.50
	Flood	----	----	----	1.95	0.80	8.50	0.82	0.57	8.50	1.91	1.05	8.50	0.54	0.41	8.50
4	Ebb	1.25	0.85	2.00	1.20	0.90	2.25	0.88	0.51	2.00	1.09	0.61	2.20	0.82	0.55	2.20
	Flood	2.10	0.95	8.40	2.40	1.05	8.65	2.04	1.10	8.50	1.91	0.85	8.60	1.72	1.04	8.70
5	Ebb	1.65	1.10	2.75	----	----	----	0.60	0.35	2.50	----	----	----	1.02	0.55	2.50
	Flood	1.60	0.90	8.50	----	----	----	0.48	0.36	8.60	----	----	----	0.82	0.55	8.50
6	Ebb	0.70	0.55	2.75	1.90	1.30	2.50	1.66	0.96	2.50	1.79	1.14	2.25	1.47	1.00	2.50
	Flood	0.90	0.60	8.75	2.00	0.90	8.25	1.60	0.89	8.20	2.04	1.03	8.20	1.28	0.84	8.50
7	Ebb	1.45	1.10	2.50	1.60	1.15	2.50	1.53	0.95	2.50	1.34	0.92	2.50	1.53	0.94	2.50
	Flood	1.55	0.85	8.25	1.70	0.80	8.50	1.41	0.76	8.40	1.41	0.91	8.50	1.49	0.89	8.50
8	Ebb	----	----	----	1.90	1.45	2.60	1.53	1.05	2.50	2.17	1.56	2.60	1.53	1.06	2.50
	Flood	----	----	----	2.00	0.85	8.50	1.22	0.57	8.50	2.17	1.27	8.50	1.15	0.57	8.30
9	Ebb	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Flood	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Station No.	Direction of Flow	Plan 3D Max Veloc	Plan 3D Avg Veloc	Plan 3D Time of Slack	Plan 3H Max Veloc	Plan 3H Avg Veloc	Plan 3H Time of Slack	Plan 4 Max Veloc	Plan 4 Avg Veloc	Plan 4 Time of Slack	Plan 5 Max Veloc	Plan 5 Avg Veloc	Plan 5 Time of Slack	Plan 6 Max Veloc	Plan 6 Avg Veloc	Plan 6 Time of Slack
2	Ebb	2.10	1.21	2.60	1.79	1.22	3.00	2.15	1.30	2.75	2.15	1.35	2.75	----	----	----
	Flood	0.75	0.55	8.20	1.15	0.68	8.00	1.25	0.75	8.25	1.40	0.75	8.25	----	----	----
3	Ebb	0.60	0.30	2.40	0.54	0.34	1.00	1.55	1.00	2.50	1.35	1.00	2.50	0.90	0.70	2.50
	Flood	0.54	0.48	8.40	1.15	0.65	7.50	1.70	0.95	8.50	1.70	0.80	8.50	1.20	0.70	8.50
3X	Ebb	1.91	1.24	2.80	1.72	1.01	2.50	----	----	----	----	----	----	----	----	----
	Flood	1.15	0.73	8.50	2.61	1.22	8.00	----	----	----	----	----	----	----	----	----
4	Ebb	0.82	0.61	2.00	1.02	0.66	2.00	----	----	----	1.45	0.80	2.35	1.20	0.75	2.25
	Flood	2.36	0.87	8.50	2.27	1.07	8.00	----	----	----	1.70	0.75	8.20	1.85	0.85	8.50
5	Ebb	0.26	0.19	2.40	----	----	----	2.00	1.40	2.75	1.80	1.25	2.65	1.40	1.05	2.50
	Flood	0.39	0.21	9.00	----	----	----	2.15	1.20	8.20	1.90	0.95	8.35	1.25	0.75	8.50
6	Ebb	1.79	1.16	2.50	1.79	1.33	2.50	----	----	----	0.65	0.50	2.75	0.50	0.40	2.25
	Flood	1.85	1.08	8.20	2.55	1.31	3.00	----	----	----	0.55	0.45	8.75	0.70	0.50	8.25
7	Ebb	1.53	1.02	2.50	1.34	0.82	2.50	1.50	1.05	2.50	1.35	0.95	2.50	1.40	0.95	2.50
	Flood	1.34	0.70	8.40	1.28	0.83	8.00	1.35	0.85	8.25	1.45	0.75	8.30	1.55	0.90	8.30
8	Ebb	2.04	1.37	2.50	2.06	1.30	2.50	----	----	----	----	----	----	----	----	----
	Flood	1.60	0.36	8.40	2.36	1.25	8.00	----	----	----	----	----	----	----	----	----
9	Ebb	----	----	----	----	----	----	----	----	----	----	----	----	1.20	0.80	2.50
	Flood	----	----	----	----	----	----	----	----	----	----	----	----	1.00	0.70	8.50

Notes: Flood slack is slack following high water; ebb slack is slack following low water.
Time is in hours after moon's transit of South Amboy meridian.

Table 6

MODEL SHOALING IN SECOND SERIES OF TESTS

Test	Section 1 Mate-rial	Section 1 Index	Section 2 Mate-rial	Section 2 Index	Section 3 Mate-rial	Section 3 Index	Section 4 Mate-rial	Section 4 Index	Section 5 Mate-rial	Section 5 Index	Sec. 3,4,&5 Mate-rial	Sec. 3,4,&5 Index	Section 6 Mate-rial	Section 6 Index	Section 7 Mate-rial	Section 7 Index	Below Sec.1 Mate-rial	Below Sec.1 Index	Plan Index*	Total Mat. Injected	Total Mat. Recovered*
	Material Recovered (in Cu Cm) by Sections** and Shoaling Indices																				
Base	1470	1.00	3690	1.00	1765	1.00	400	1.00	865	1.00	3030	1.00	---	----	----	----	3160	1.00	1.00	19,000	8190
Plan 3	800	0.54	1010	0.27	1290	0.73	535	1.34	970	1.12	2795	0.92	320	----	1070	----	3620	1.15	0.51	19,000	4170
Plan 4	1430	0.97	1475	0.40	140	0.08	275	0.69	800	0.93	1215	0.40	---	----	----	----	4240	1.34	0.50	19,000	4120
Plan 5	2605	1.77	2200	0.60	1240	0.70	353	0.88	657	0.76	2250	0.74	---	----	----	----	4940	1.56	0.86	19,000	7055
Plan 6	820	0.56	3720	1.01	1475	0.84	475	1.18	960	1.11	2910	0.96	---	----	----	----	1450	0.46	0.91	19,000	7450

* Does not include material below section 1, or material deposited in sections 3 and 4 during plan 3.
** Section locations shown on fig. 13.

Table 7

MODEL SHOALING IN SECOND SERIES OF TESTS

Test	Section 1 Mate-rial	Section 1 Index	Section 2 Mate-rial	Section 2 Index	Section 3 Mate-rial	Section 3 Index	Section 4 Mate-rial	Section 4 Index	Section 5 Mate-rial	Section 5 Index	Sec. 3,4,&5 Mate-rial	Sec. 3,4,&5 Index	Section 6 Mate-rial	Section 6 Index	Section 7 Mate-rial	Section 7 Index	Below Sec.1 Mate-rial	Below Sec.1 Index	Plan Index*	Total Mat. Injected	Total Mat. Recovered*
	Material Recovered (in Cu Cm) by Sections** and Shoaling Indices																				
Base	1495	1.00	2600	1.00	1740	1.00	360	1.00	685	1.00	2785	1.00	----	----	----	----	2380	1.00	1.00	19,000	6880
Plan 3A	1540	1.03	1120	0.43	1360	0.78	775	2.15	660	0.96	2795	1.00	925	----	1080	----	1385	0.56	0.77	19,000	5325
Plan 3B	1320	0.88	1200	0.46	1010	0.58	340	0.94	1180	1.72	2530	0.91	620	----	970	----	2850	1.20	0.77	19,000	5290
Plan 3C	1715	1.15	1620	0.62	2100	1.21	970	2.69	1295	1.89	4365	1.57	1195	----	1425	----	1600	0.67	1.05	19,000	7250
Plan 3D	2000	1.34	1105	0.43	1130	0.65	575	1.60	1150	1.68	2855	1.03	830	----	1300	----	2380	1.00	0.93	19,000	6385

* Does not include material below section 1, or material deposited in sections 3 and 4 during the plan tests.
** Section locations shown on fig. 13.

Table 8

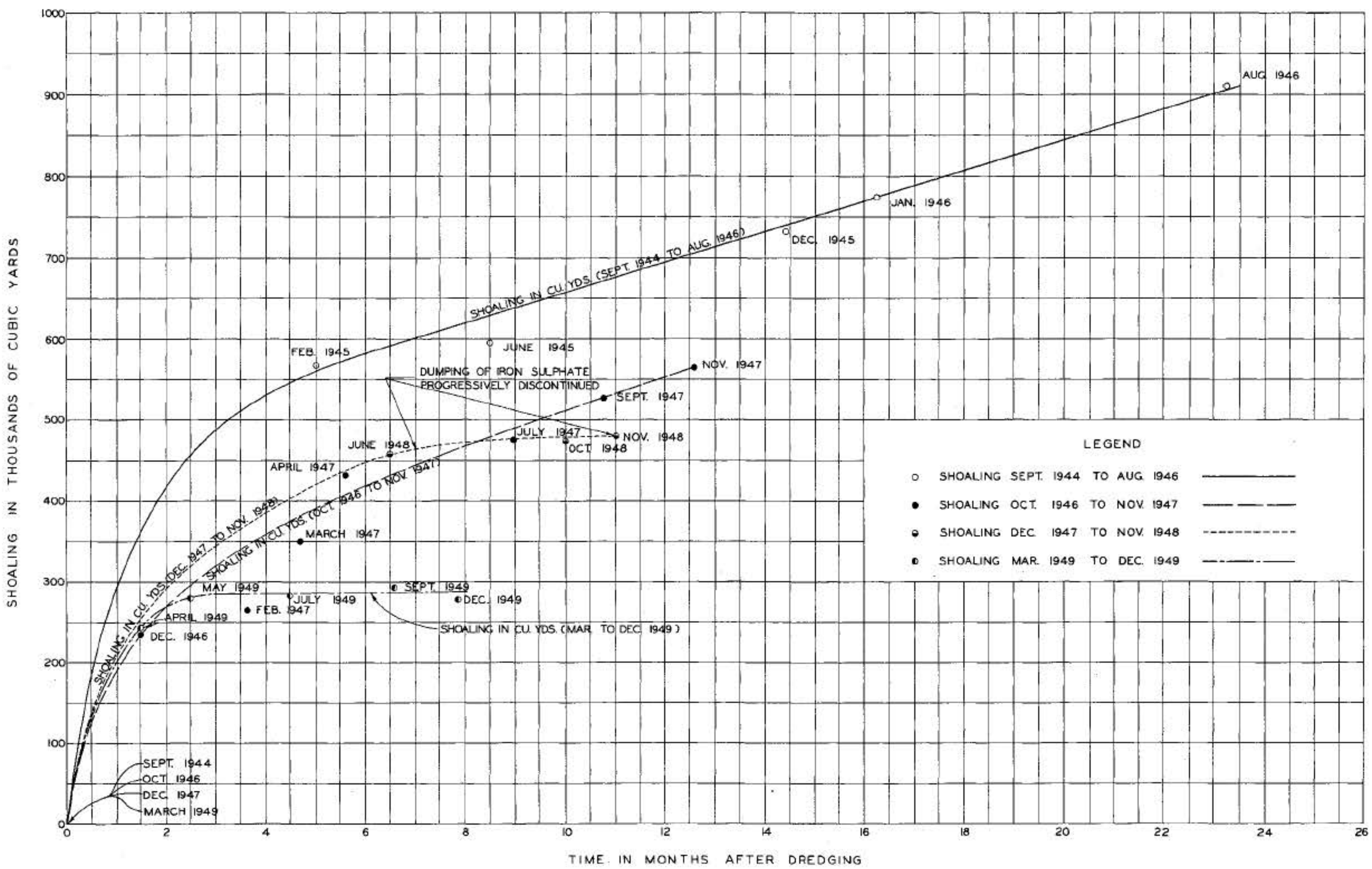
MODEL SHOALING IN MODIFIED PLANS

	Material Recovered (in Cu Cm) by Sections** and Shoaling Indices																				
	Section 1		Section 2		Section 3		Section 4		Section 5		Sec. 3,4,&5		Section 6		Section 8		Below Sec.1				
Test	Material	Index	Material	Index	Material	Index	Material	Index	Material	Index	Material	Index	Material	Index	Material	Index	Material	Index	Plan Index*	Total Mat. Injected	Total Mat. Recovered*
Base	1330		2900		1340		300		500		2140				310		1800			19,000	8480
Plan 3	923	0.70	1660	0.57	945	0.70	420	1.40	898	1.80	2263	1.06	458		578	1.87	2910	1.62	0.62	19,000	3939
Plan 3D	1216	0.91	1880	0.65	1170	0.87	763	2.54	780	1.56	2713	1.27	1232		694	2.24	2016	1.12	0.80	19,000	5108
Plan 3G	1295	0.98	1292	0.45	800	0.60	615	2.05	965	1.93	2380	1.11	1134		825	2.66	1878	1.04	0.73	19,000	4686
Plan 3H	946	0.71	800	0.28	507	0.38	558	1.87	1088	2.18	2153	1.00	532		810	2.61	3014	1.67	0.53	19,000	3366

* Does not include material below section 1, or material deposited in sections 3, 4, and 8 during the plan tests.

** Section locations are shown on fig. 13.

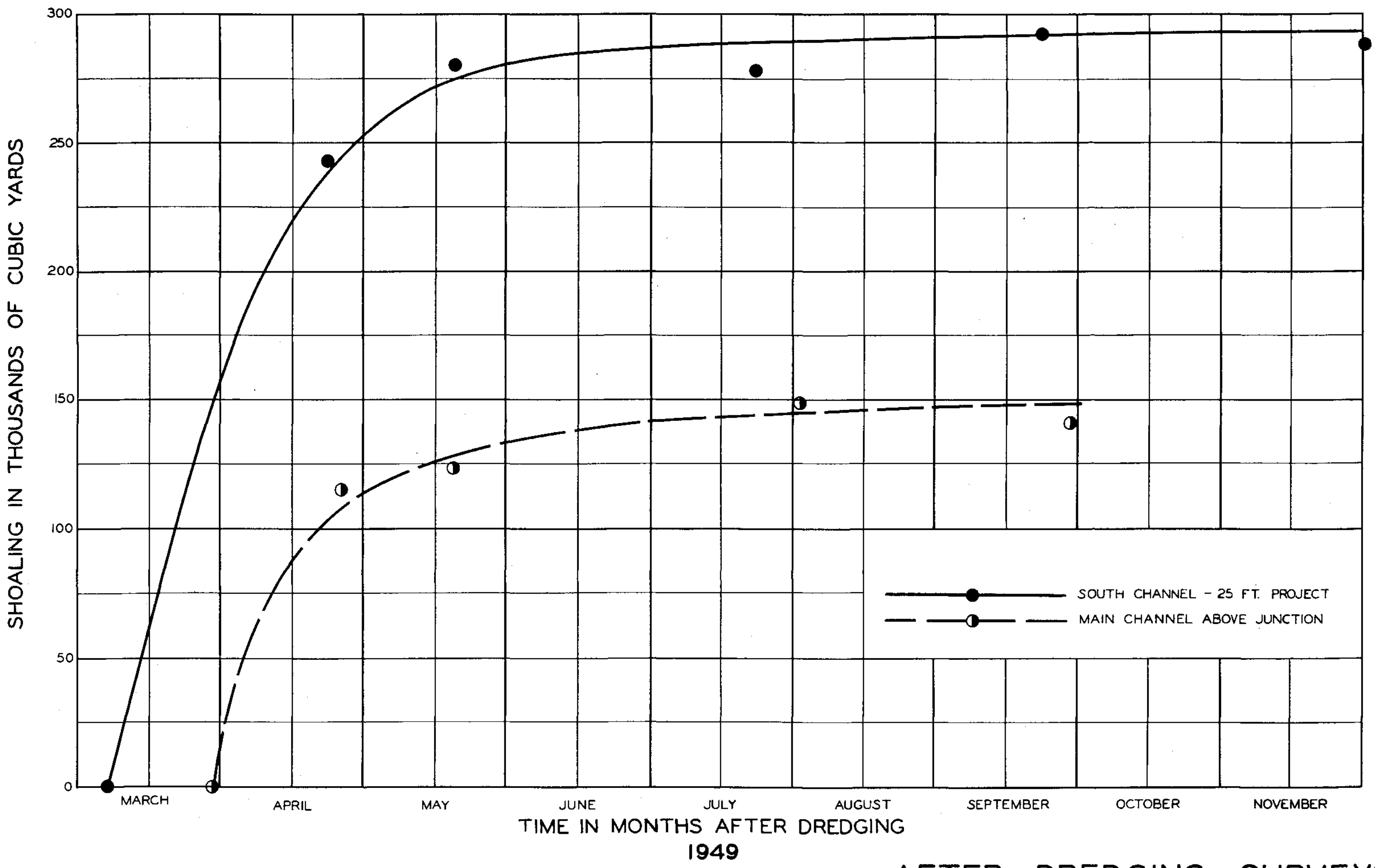
PLATES



SHOALING - SOUTH CHANNEL
25 - FOOT PROJECT

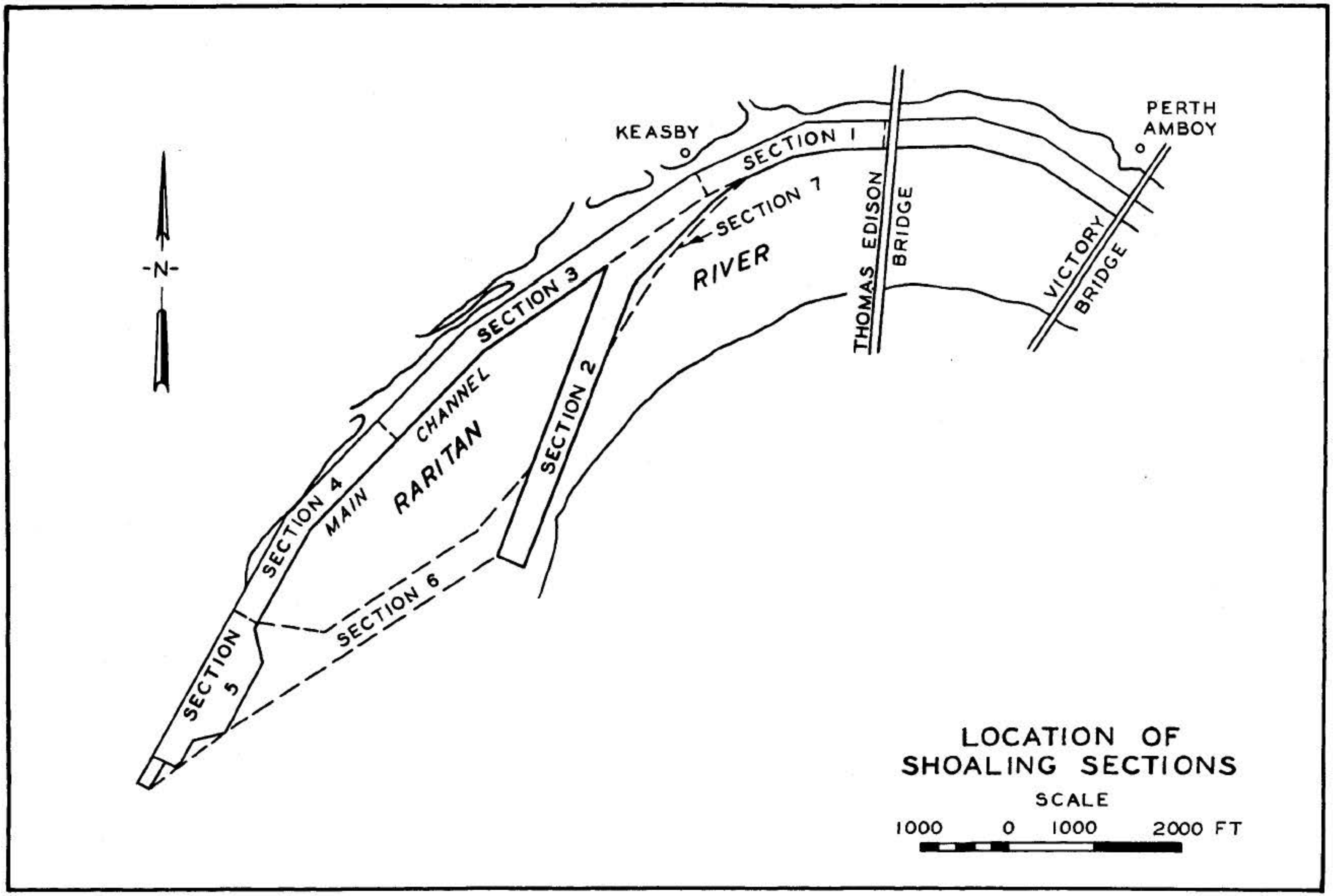
PLATE 1

PLATE 2



AFTER DREDGING SURVEYS

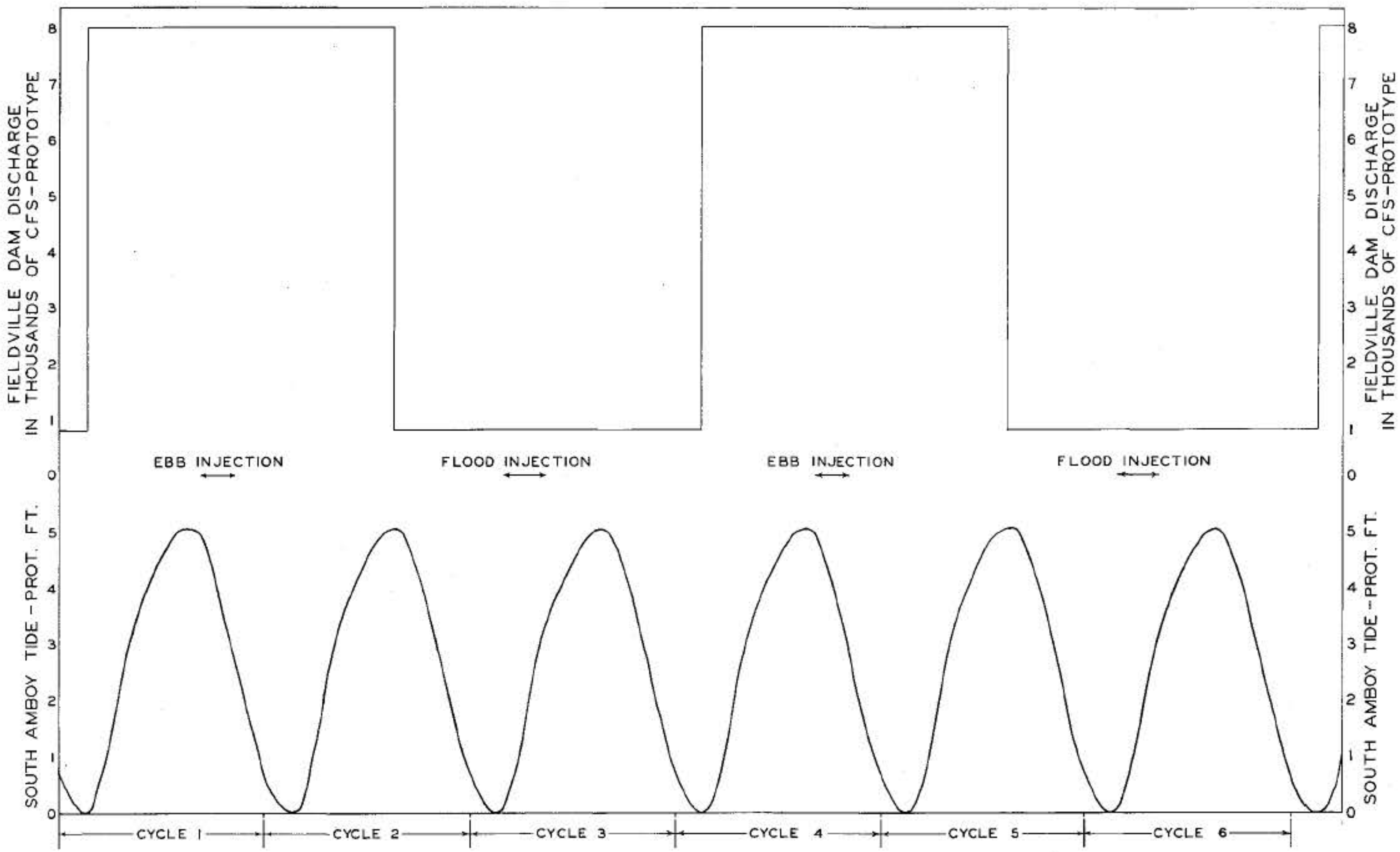
MAIN CHANNEL AND SOUTH CHANNEL
25 FT. PROJECT



LOCATION OF SHOALING SECTIONS

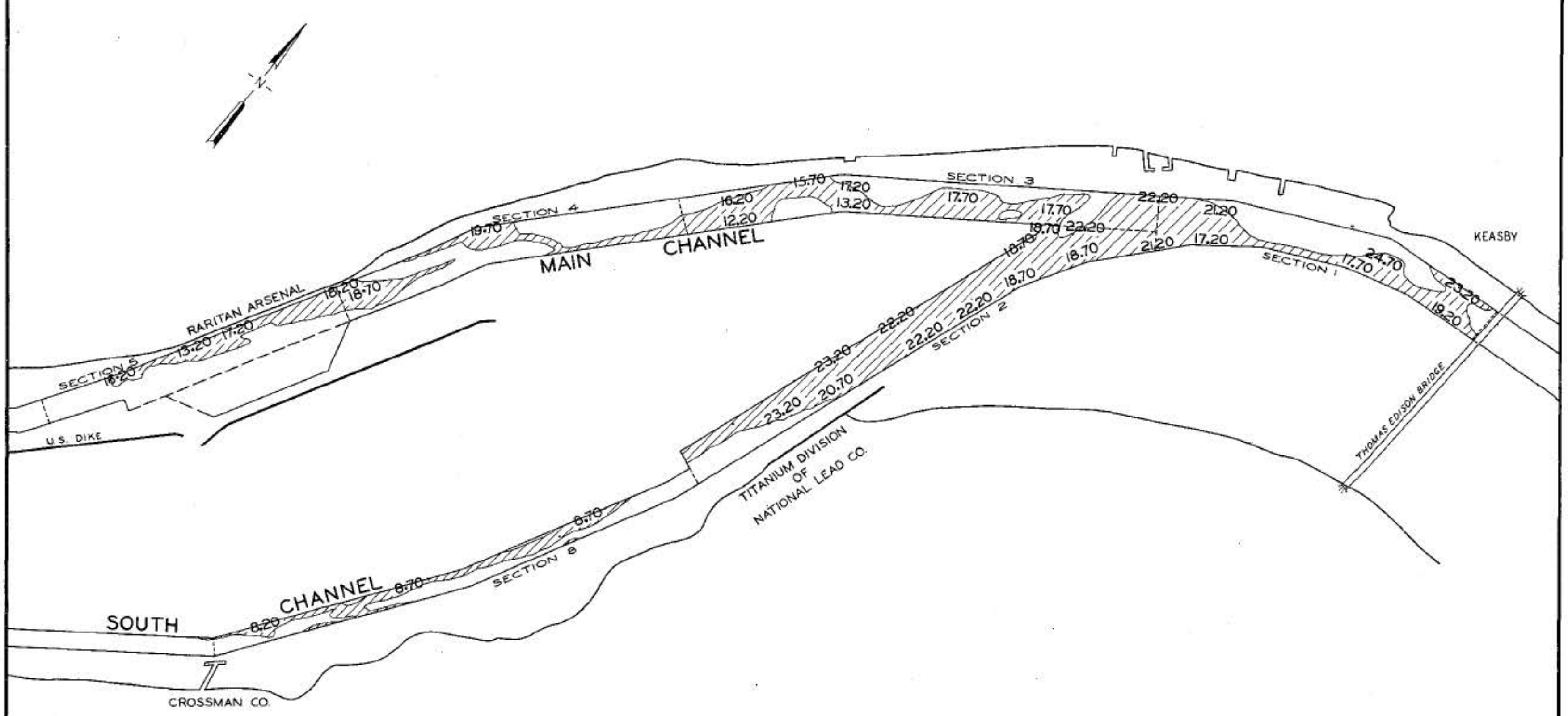
PLATE 3

PLATE 4



NOTE: ELEVATIONS ARE IN TERMS OF MLW AT SOUTH AMBOY.

RELATION BETWEEN TIDE, DISCHARGE, AND SILT INJECTION



NOTE

SOUNDINGS ARE REFERRED TO MLW
AT SOUTH AMBOY

LEGEND

SHOAL AREAS

SHOALING PATTERN AT END OF TEST

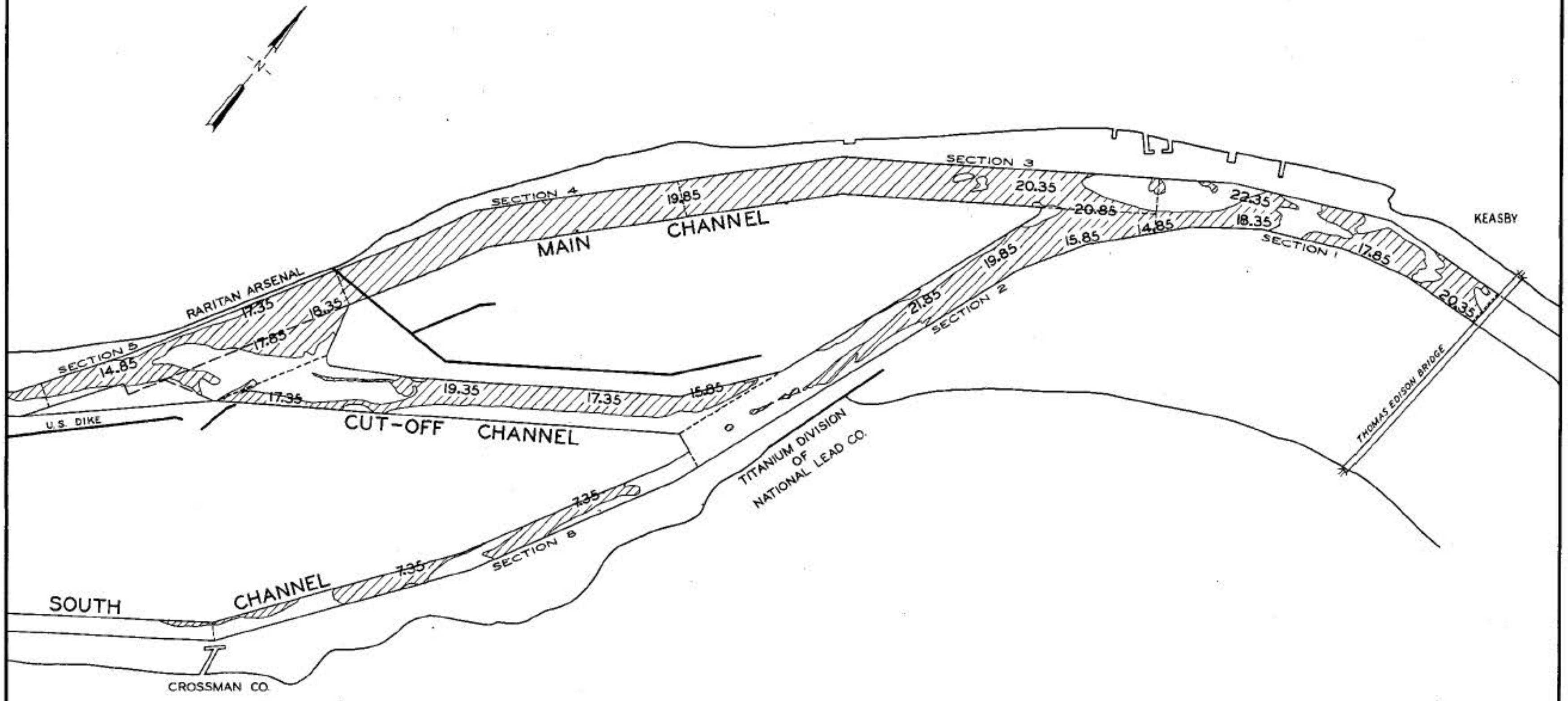
BASE TEST

SCALE

500 0 500 1000 1500FT

PLATE 5

PLATE 6



SHOALING PATTERN AT END OF TEST

PLAN 3-MODIFIED

SCALE

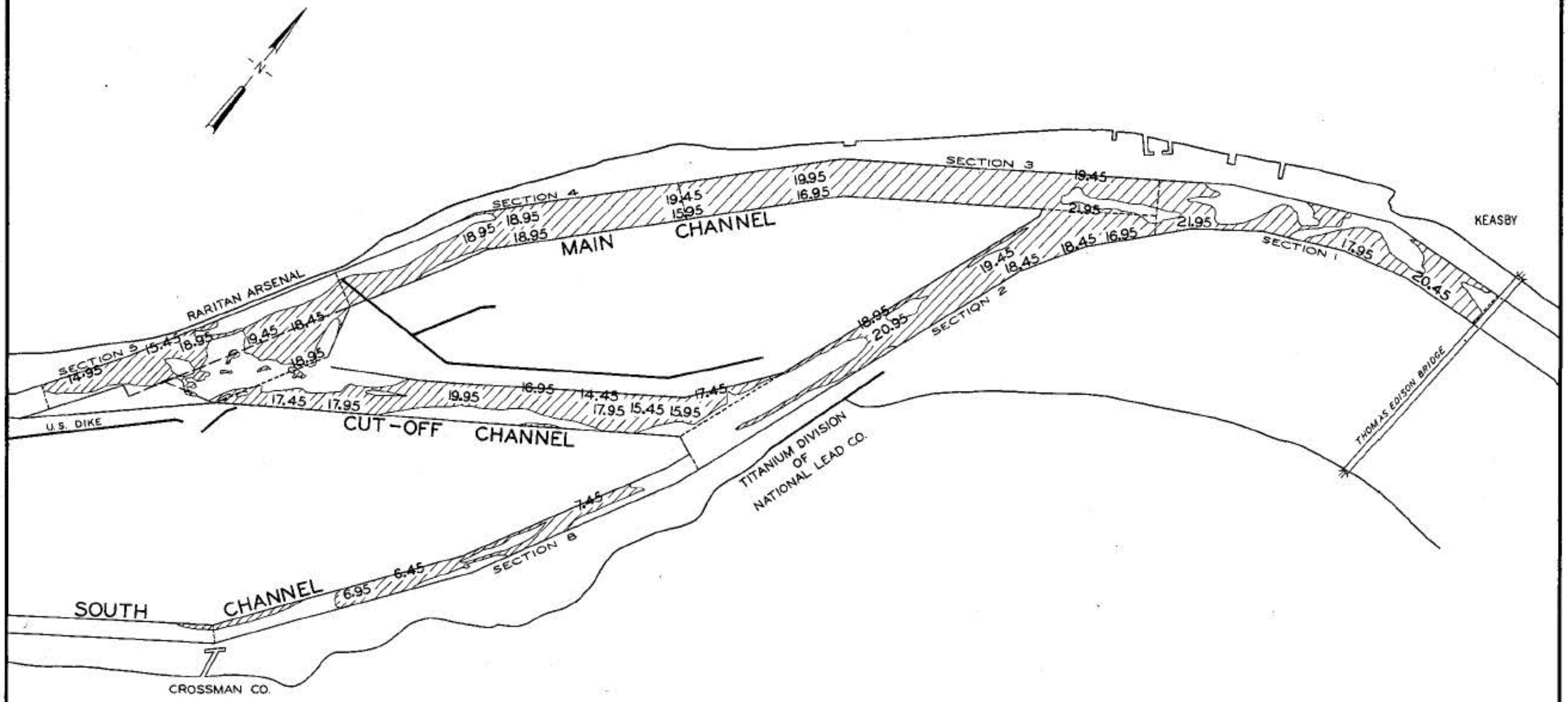
500 0 500 1000 1500FT

NOTE

SOUNDINGS ARE REFERRED TO MLW AT SOUTH AMBOY

LEGEND

SHOAL AREAS



NOTE

SOUNDINGS ARE REFERRED TO MLW AT SOUTH AMBOY

LEGEND

▨ SHOAL AREAS

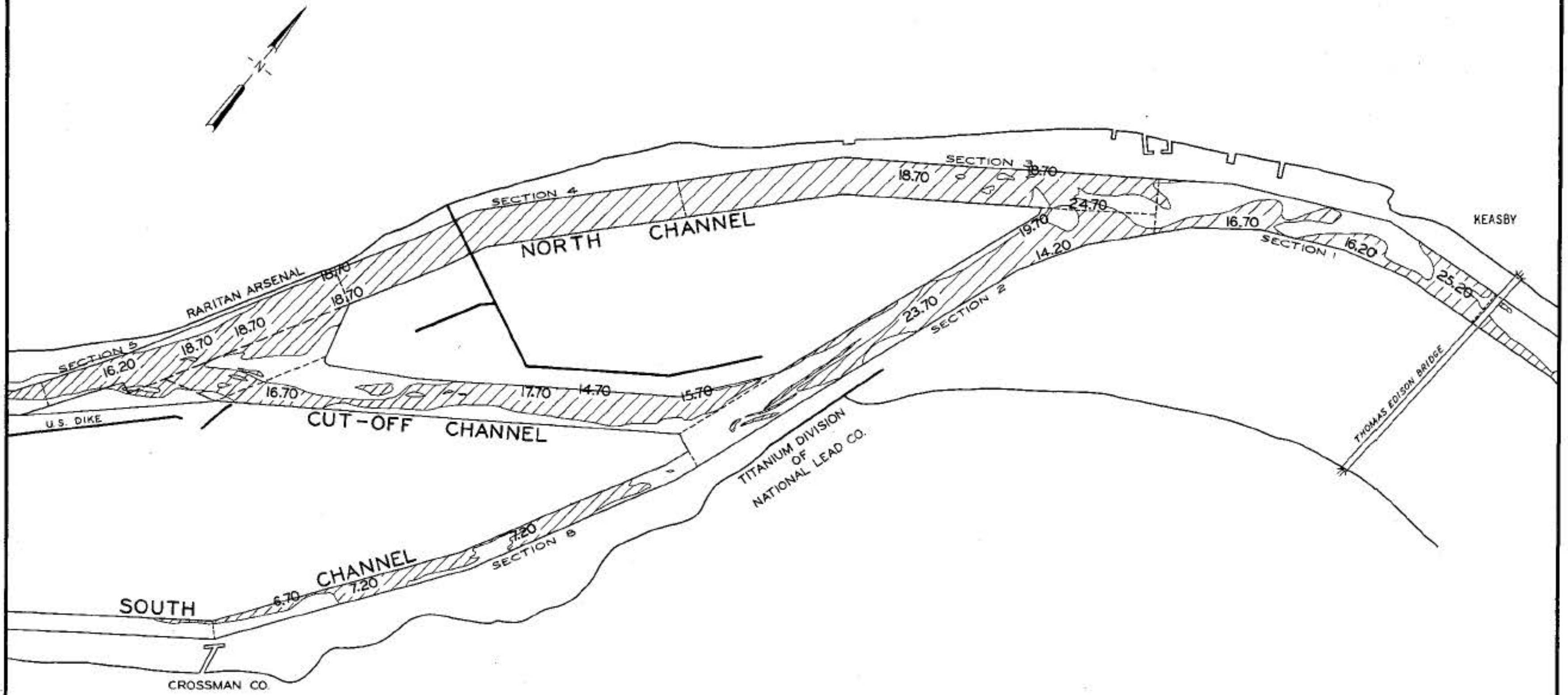
SHOALING PATTERN AT END OF TEST

PLAN 3D-MODIFIED

SCALE

500 0 500 1000 1500FT

PLATE 8



NOTE

SOUNDINGS ARE REFERRED TO MLW AT SOUTH AMBOY

LEGEND

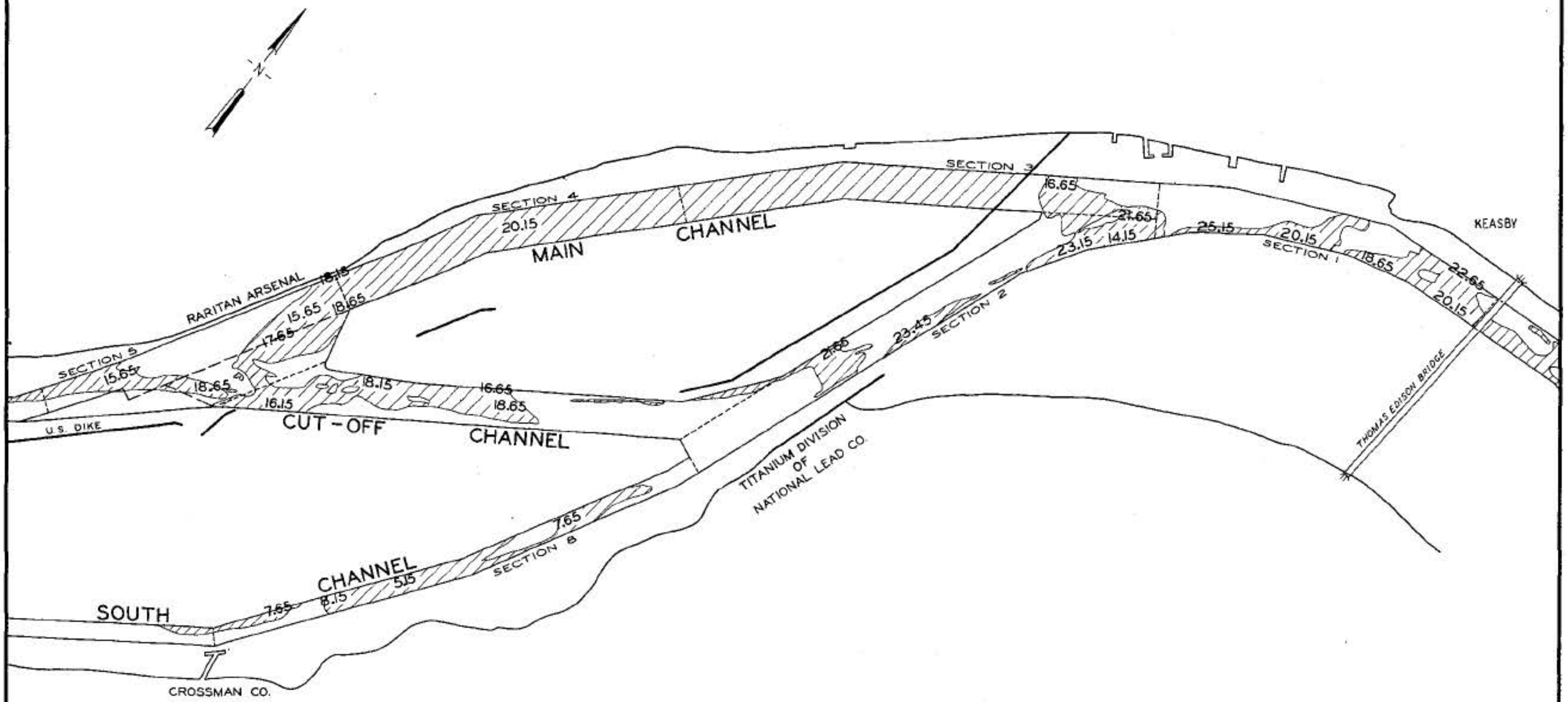
SHOAL AREAS

SHOALING PATTERN AT END OF TEST

PLAN 3G

SCALE

500 0 500 1000 1500 FT



NOTE

SOUNDINGS ARE REFERRED TO MLW AT SOUTH AMBOY

LEGEND

SHOAL AREAS

SHOALING PATTERN AT END OF TEST

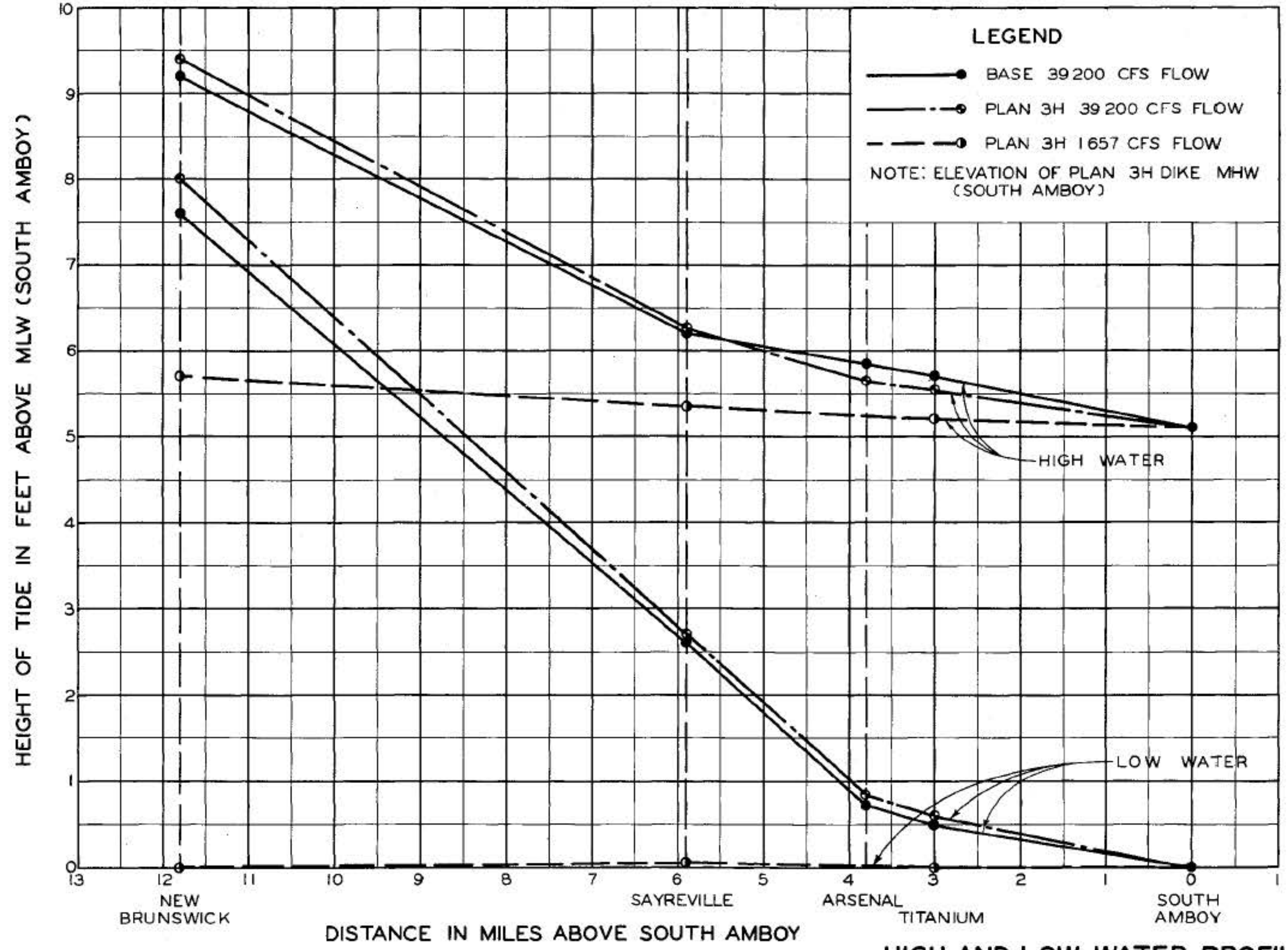
PLAN 3H

SCALE

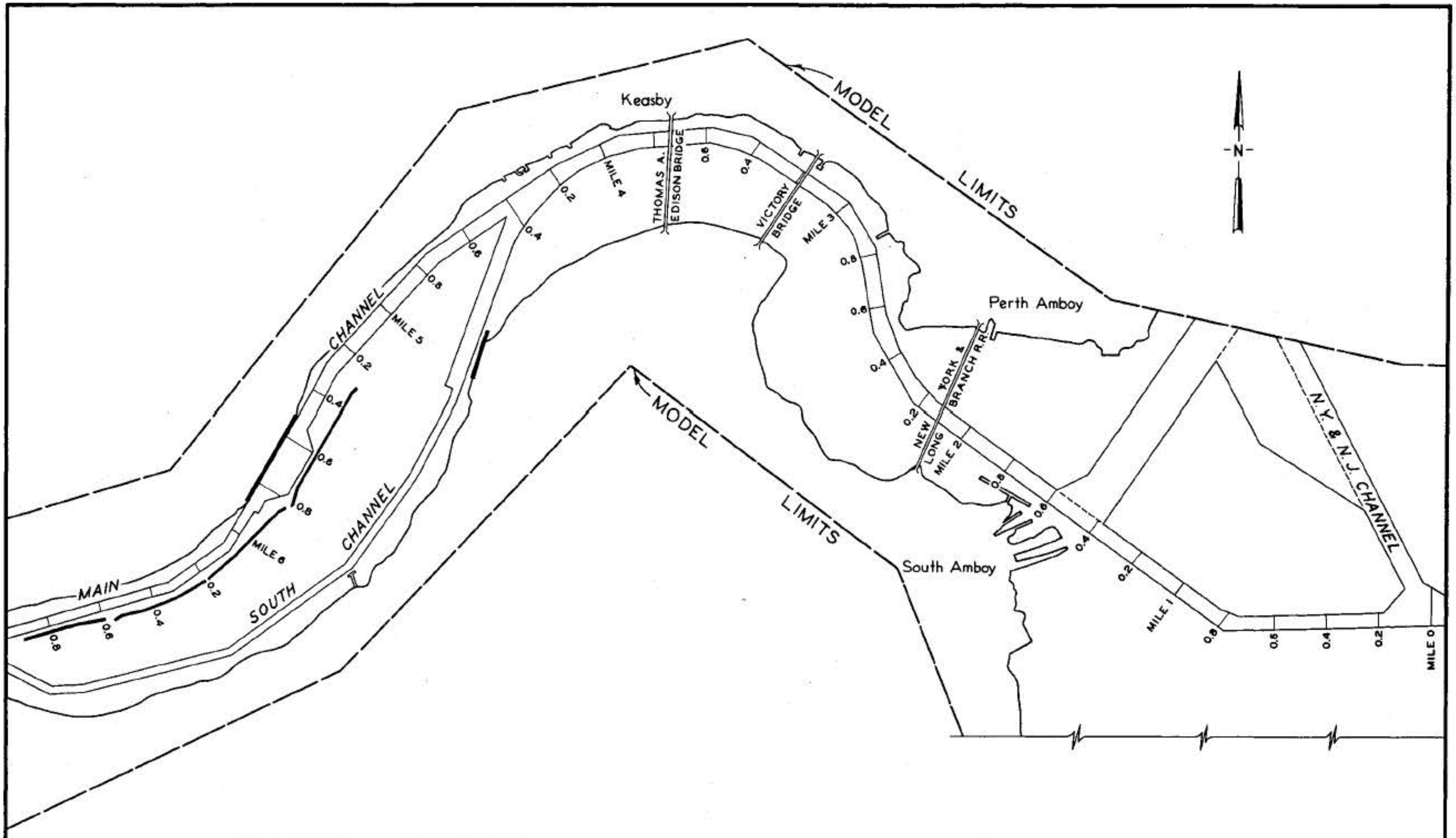
500 0 500 1000 1500 FT

PLATE 9

PLATE 10



HIGH AND LOW WATER PROFILES
PLAN 3H



NOTE: MILE ZERO IS INTERSECTION OF RARITAN RIVER CHANNEL AND NEW YORK AND NEW JERSEY CHANNEL.

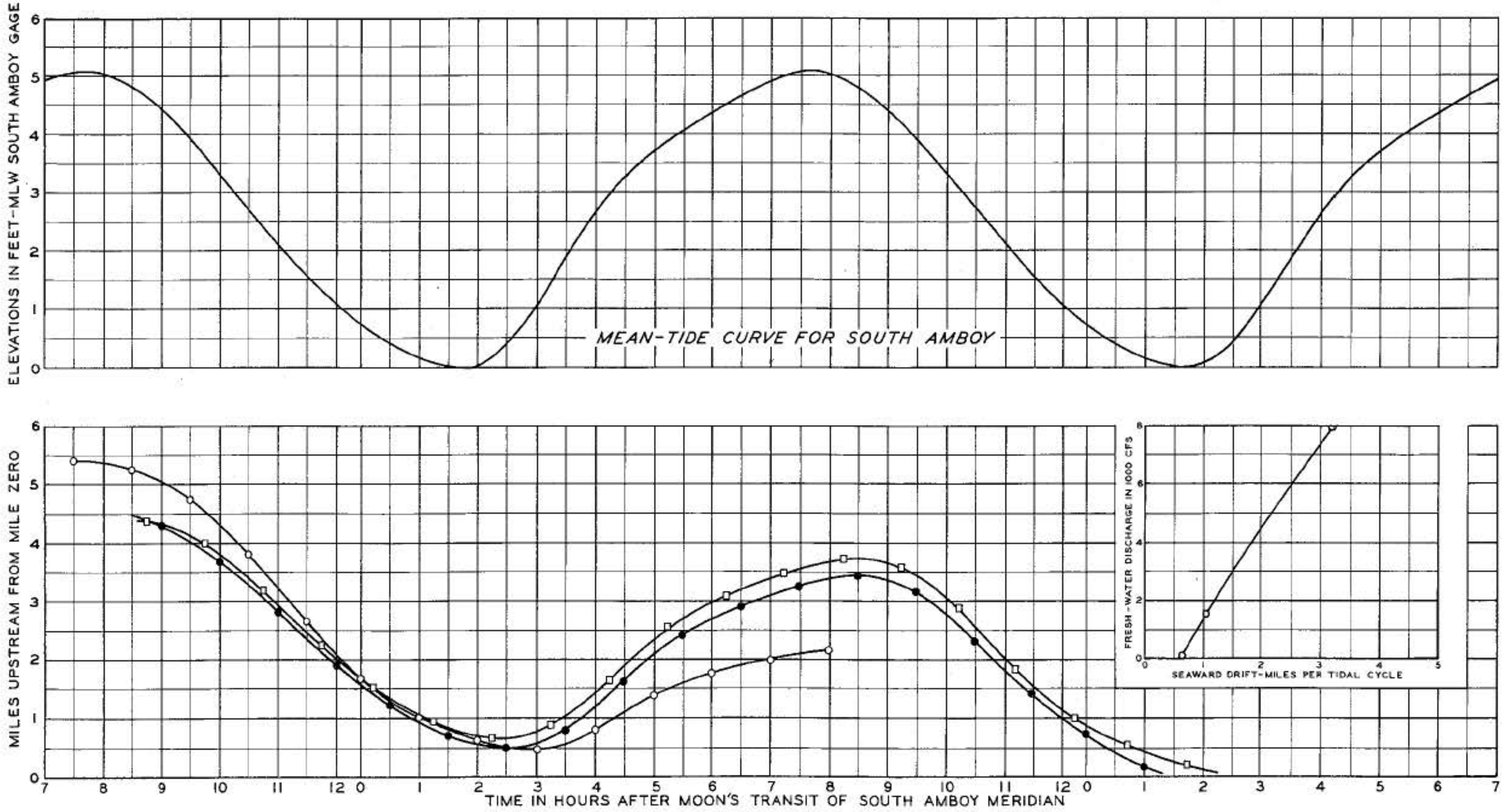
CHANNEL STATIONS IN MILES

SCALE

1000 0 1000 2000 3000 FT

PLATE 11

PLATE 12



LEGEND

- ○ FRESH-WATER DISCHARGE 8000 CFS
- ● FRESH-WATER DISCHARGE 1500 CFS
- □ FRESH-WATER DISCHARGE 100 CFS

NOTE: MILEAGE IS SHOWN ON PLATE 11. MILE 0 IS AT THE INTERSECTION OF RARITAN CHANNEL WITH NEW YORK AND NEW JERSEY CHANNEL. DRIFT OBSERVATIONS WERE OBTAINED WITH A POLE FLOAT SUBMERGED TO A DEPTH OF 16 FT.

DRIFT OBSERVATIONS